Exploration of Digestive Diseases

Open Exploration

Open Access Review

Microbiota and iron metabolism

Natalia Baryshnikova[1,2,3]*, Yury Uspenskiy[1,2], Valeria Novikova[1]

[1]Laboratory of Medico-Social Pediatric Problems, Saint Petersburg State Pediatric Medical University, 194100 Saint Petersburg, Russia

[2]Internal Diseases Department of Stomatological Faculty, Pavlov First Saint Petersburg State Medical University, 197022 Saint Petersburg, Russia

[3]Molecular Microbiology Department, Institute of Experimental Medicine, 197022 Saint Petersburg, Russia

***Correspondence:** Natalia Baryshnikova, Internal Diseases Department of Stomatological Faculty, Pavlov First Saint Petersburg State Medical University, 197022 Saint Petersburg, Russia. baryshnikova_nv@mail.ru

Academic Editor: Raquel Soares, University of Porto, Portugal

Received: July 3, 2025 **Accepted:** July 28, 2025 **Published:** August 8, 2025

Cite this article: Baryshnikova N, Uspenskiy Y, Novikova V. Microbiota and iron metabolism. Explor Dig Dis. 2025;4:100585. https://doi.org/10.37349/edd.2025.100585

Abstract

This article addresses the current understanding of the bidirectional relationship between iron metabolism and the gut microbiota. Both iron deficiency and iron overload in the gut can negatively affect the composition and function of the intestinal microbiota. Conversely, beneficial members of the colonic microbiota play a key role in enhancing systemic iron absorption. Particular attention is given to the potential use of microbiota-modulating agents for the correction of colonic dysbiosis as part of a comprehensive therapeutic approach to iron deficiency/overload conditions. Therefore, these interventions, by supporting microbiota restoration and reduction of intestinal inflammation, may also offer novel therapeutic avenues for disorders of iron metabolism.

Keywords

Intestinal microbiota, probiotics, prebiotics, iron deficiency anemia, iron

Introduction

Iron deficiency remains a widespread global health issue, affecting over two billion people worldwide [1]. It is estimated that about 40% of the population in developing countries and about 10% in developed countries suffer from iron deficiency [2]. This micronutrient plays a critical and universal role in numerous physiological processes, including protein and enzymatic functions, energy production, and is essential for fundamental biological mechanisms such as cellular growth and differentiation [3]. Iron deficiency impairs the function of multiple organ systems, most notably the central nervous, endocrine, and cardiovascular systems. It leads to the development of iron deficiency anemia (IDA) of varying severity, reduced physical performance, and a significant decline in quality of life [4]. In children, iron deficiency is particularly concerning due to its impact on growth and neurodevelopment [5, 6].

The principal causes of iron deficiency include inadequate dietary intake of iron-rich foods, increased physiological demand, and impaired absorption due to acquired or genetic factors. The literature addressing intestinal iron absorption presents conflicting views regarding the valence state of iron that is preferentially absorbed—whether ferrous (Fe^{2+}) or ferric (Fe^{3+}) [7–9]. However, numerous studies highlight the critical importance of the solubility of orally administered iron in the intestinal lumen as a key determinant of its bioavailability [10]. Moreover, iron valence is not as important as the ability of a person to absorb iron, the causes of iron metabolism disorders, as well as the features of the intestinal microbiota.

Iron metabolism and its role in gut microbiota

Recent studies have highlighted the complex interplay between iron bioavailability, absorption, and the activity of microorganisms in the large intestine, emphasizing the role of the gut microbiota in regulating iron homeostasis [11]. Only approximately 10% of dietary iron is absorbed by the human body, while the remaining 90% is excreted in feces, potentially influencing the microbial composition of the colon [12]. Depending on dietary intake, about 15% of ingested iron is absorbed in the duodenum, with the remainder passing into the colon, where it may serve as a nutrient source for commensal bacteria.

Colonic bacteria have evolved mechanisms to acquire iron, including the production of high-affinity iron-chelating molecules known as siderophores, as well as transferrin and lactoferrin receptors that facilitate the uptake of free iron in the gut lumen. Since iron is essential for the survival and proliferation of nearly all bacterial species [13], the amount of unabsorbed iron reaching the colon can significantly influence microbial population dynamics [14]. Thus, changes in systemic iron homeostasis can affect the iron content in the intestinal lumen and, consequently, the composition of the intestinal microbiota [15].

Experimental studies in mice have shown that iron regulatory protein 2 (*Irp2*) and mutated *Hfe* genes (involved in hereditary hemochromatosis) play significant roles in iron regulation. Compared to wild-type controls, mice with deletions in *Irp2* or *Hfe* genes exhibited substantial changes in gut microbiota composition, underscoring the influence of host iron metabolism on microbial ecology [15]. Iron deficiency has been associated with an increased risk of intestinal infections due to its impact on microbiota structure [16]. Conversely, iron overload also exerts adverse effects. Jaeggi et al. [17] demonstrated that iron supplementation in infants led to a reduction in Bifidobacteria, an increase in Enterobacteriaceae (including pathogenic *E. coli* strains), and elevated fecal calprotectin levels, indicating intestinal inflammation. The virulence of many pathogens is closely linked to iron availability [18].

Several studies suggest that both iron deficiency and iron overload can contribute to colonic dysbiosis, inflammation, and the development of colorectal cancer [19–21]. Disruptions of the gut microbiota in hemochromatosis have been linked to altered ferroportin function. This iron-exporting protein, encoded by the *SLC40A1* gene, is responsible for transporting iron from enterocytes and macrophages into the bloodstream. Mutations in *SLC40A1* lead to a hemochromatosis phenotype characterized by hepatic iron overload and microbiota alterations [22–24]. An iron-rich gut environment favors the expansion of Proteobacteria, and studies conducted with children demonstrated that excess iron contributes to chronic inflammation and the proliferation of pathogenic bacteria [25].

Inflammatory bowel diseases (IBDs) can disrupt both iron absorption and gut microbiota balance. The resulting excess of iron in the intestinal lumen may contribute to the appearance of pathobionts—commensal bacteria that acquire pathogenic traits under dysbiotic conditions [26]. Lee et al. [27] further reported that in patients with IBDs and anemia, oral iron therapy produced distinct alterations in bacterial phylotypes and fecal metabolites compared to intravenous iron therapy. Notably, oral iron administration resulted in reduced levels of *Faecalibacterium prausnitzii* and *Ruminococcus bromii* [27]. *F. prausnitzii* is a well-recognized member of the healthy gut microbiota, known for its anti-inflammatory properties mediated by butyrate production [28, 29]. Similarly, *R. bromii* contributes to butyrate production through the fermentation of resistant starch [30]. A decrease in the abundance of these beneficial taxa is associated with sustained intestinal inflammation and may increase the risk of colorectal cancer [31]. These pathobionts are implicated in the etiology of both IBD and colorectal cancer [32]. However, not all studies

confirm a universally negative effect of iron supplementation. For instance, an experimental study in rats revealed that iron-deficient rats had significantly lower concentrations of butyrate and propionate in the cecum (this may be due to lower levels of *Roseburia* spp. and the *Eubacterium rectale* group) and exhibited pronounced alterations in microbial composition [33]. In contrast, prolonged high-dose iron supplementation (50 mg Fe, 4 days per week for 266 days) did not induce intestinal inflammation, and the abundance of major microbial groups and short-chain fatty acid (SCFA) concentrations remained stable [34]. It can be assumed that in IBDs, IDA is associated not only with blood loss through stool, but also with impaired iron metabolism in the intestine, and concomitant changes in the microbiota confirm the effect of these pathogenetic patterns. Also, it is important that in patients with active IBDs, iron absorption is reduced, but in patients with IBDs in remission, it is normal [13]. Therefore, for prophylaxis of gut microbiota disorders in active IBDs, intravenous iron intake is preferred, and in IBDs in remission, oral iron can be administered. It is important to investigate the effect of iron deficiency and iron therapy on redox status, intestinal microbiota, and possible interactions between them because it also promotes negative effects in IBD patients [35].

Iron metabolism and the role of gut microbiota changes

While systemic iron levels can influence the composition of the intestinal microbiota, increasing evidence suggests that the microbiota itself actively participates in the regulation of iron absorption and homeostasis [36]. Studies in germ-free (axenic) mice have demonstrated the increase in the expression of divalent metal transporter 1 (DMT1) and duodenal cytochrome B (DCYTB) in 8–10-fold, reduction in ferroportin expression in the duodenum by twofold, and decreased iron levels in enterocytes. Following colonization with commensal bacteria, iron accumulation in intestinal epithelial cells increased significantly [37].

A study conducted among young women in southern India found that lower iron status positively correlated with decreased levels of fecal *Lactobacillus* spp. [38]. This relationship may be attributed to the ability of lactic acid—produced by *Lactobacillus* species—to enhance the bioavailability of dietary iron [39]. Similarly, other research has shown that probiotic strains such as *L. fermentum* can promote intestinal iron absorption. This effect has been linked to the production of *p*-hydroxyphenyllactic acid by *Lactobacilli*, which facilitates the reduction of ferric (Fe^{3+}) to ferrous (Fe^{2+}) iron—a necessary step for absorption via DMT1 channels in enterocytes [40]. The ability of *Lactobacillus*-based probiotics to improve iron bioavailability underscores their potential as adjunctive tools in clinical nutrition and anemia management [39].

Furthermore, the pH of the colonic lumen is an important factor that influences iron absorption. Several gut microorganisms ferment galactooligosaccharides, which leads to acidification of the gut environment, which increases the solubility and absorption of iron. Therefore, dietary inclusion of acetic acid-producing probiotic products may contribute to improved iron absorption through this pH-lowering mechanism [41].

Iron imbalance and its correction: which ways and types of iron administration can we choose?

To correct iron deficiency, various strategies may be employed, including the use of iron-rich foods, dietary supplements, and, in severe cases, medical interventions such as blood transfusions or erythrocyte concentrate infusions [42]. It has been well established that vegetables, meat, and meat products serve as excellent dietary sources of iron, and that fermentation of these products can enhance iron bioavailability. However, a major challenge lies not in the source of iron itself, but in the chemical form of the iron and the pathway by which it is absorbed [43].

As mentioned above, oral administration of heme iron has been shown to alter gut microbial populations, leading to dysbiosis, particularly through the reduction of butyrate-producing taxa. This is of clinical significance, as butyrate is a key SCFA with anti-inflammatory and anticarcinogenic properties. A

comparative mouse study demonstrated that oral iron supplementation exacerbated colitis and promoted adenoma formation to a greater extent than parenteral iron administration [44].

Thus, intravenous iron supplementation, by minimizing adverse microbiota alterations and intestinal inflammation, may represent a more favorable therapeutic option compared to oral iron administration.

It is actual and clinically promising to use the peptide-iron chelates (peptide-iron complex). To investigate the effects of peptide-iron chelates on gut microbiota composition and intestinal inflammation in a mouse model of IDA, animals were administered low, medium, and high doses of peptide-iron chelates and ferrous sulfate ($FeSO_4$) (1.0, 2.0, and 3.0 mg Fe/kg body weight, respectively) via oral gavage daily for four weeks [45]. Intake of peptide-iron chelates at various doses resulted in reduced inflammation and increased secretion of secretory immunoglobulin A [45]. In addition, these chelates mitigated inflammatory cell infiltration and oxidative stress in colonic tissue, thereby improving gut permeability.

16S rRNA gene sequencing demonstrated that treatment with peptide-iron chelates increased microbial diversity in the colon, reduced dysbiosis, and restored the *Firmicutes*-to-*Bacteroides* ratio. In contrast, administration of traditional $FeSO_4$ was associated with an increase in pathogenic bacteria (e.g., *Helicobacter* and *Erysipelatoclostridium*) and a decrease in beneficial taxa (e.g., *Bifidobacterium* and *Blautia*) [45, 46].

A related study explored the use of a pectin-iron complex as a delivery matrix for *L. plantarum* CIDCA 83114. The researchers evaluated the biostability of pectin-iron nanoparticles and estimated their biological activity. The results demonstrated that iron was non-toxic to the probiotic cells and did not influence bacterial viability. So, the probiotic strain can promote the dual utility for both iron delivery and bacterial stabilization. This approach presents a promising alternative for addressing iron deficiency [47]. Further innovation includes a novel formulation based on three compounds: iron oxide nanoparticles, pectin, and lactic acid bacteria. These components act synergistically to provide safe delivery of soluble iron to the gastrointestinal tract [47].

Another study focused on the synthesis of organic iron-binding compounds derived from polysaccharides. A complex composed of iron chloride-inulin-succinic anhydride-cysteine was developed, which exhibited favorable biodegradability in the presence of inulinase and strong mucoadhesive properties. These results demonstrated that such iron-binding complexes may be effective in the oral treatment of IDA or as components of iron-fortified functional foods [48].

Probiotics, other biotics, and iron imbalance correction

A balanced gut microbiota plays a critical role in optimizing iron absorption. Therefore, therapeutic strategies targeting the correction of intestinal dysbiosis—through the use of probiotics (life bacteria strains), prebiotics (compounds that stimulate the growth and activity of beneficial bacteria in the intestine), or synbiotics (probiotics and prebiotics)—are increasingly considered as part of comprehensive approaches to managing iron deficiency conditions [42, 49].

However, evidence on the efficacy of probiotic interventions in improving iron absorption remains inconsistent. A systematic review indicated that *L. plantarum* 299v may be effective for the prevention of IDA. This strain was shown to improve the absorption of non-heme dietary iron in healthy adult Europeans [39]. In contrast, Rosen et al. [50] reported that for pediatric patients, there is no significant improvement in serum ferritin levels after intake of *L. plantarum* 299v compared to a control group, suggesting strain- and context-specific variability in response.

In an animal study, the effects of multi-strain oral probiotic supplementation were evaluated in rats. This medicine contains a mixture of several probiotic strains: *B. bifidum* W23, *B. lactis* W51 and W52, *L. acidophilus* W37, *L. brevis* W63, *L. casei* W56, *L. salivarius* W24, and *Lactococcus lactis* strains W19 and W58, and was administered at low (2.5×10^9 CFU) and high (1×10^{10} CFU) doses. The results demonstrated enhanced iron-binding capacity in the high-dose group relative to controls [51].

Several studies have also reported that the intake of prebiotics and/or synbiotics correlates with improved iron bioavailability. This effect is primarily attributed to the decrease of ferric iron (Fe^{3+}) to its more absorbable ferrous form (Fe^{2+}), facilitating uptake by enterocytes [52]. For instance, in a study using Sprague-Dawley rats, dietary supplementation with unrefined galacto-oligosaccharide prebiotics over a period of 3–4 weeks significantly enhanced the intestinal absorption of calcium, magnesium, and iron [53].

A study conducted in school-aged children (9–12 years) demonstrated that synbiotic supplementation may improve iron absorption. All participants were divided into two different groups: participants in one group received iron supplementation in the form of syrup (administered twice weekly), while the other group consumed a synbiotic formulation consisting of *L. plantarum* Dad 13 and fructooligosaccharides in milk (administered six times weekly) over a 3-month period. Overall, no statistically significant differences were observed between the groups in serum iron levels or gut microbiota composition. However, a higher abundance of *E. coli* was found in children who received only the iron syrup, whereas those who consumed the synbiotic mixture exhibited increased levels of *Bifidobacterium* spp. in their feces [49].

The effect of synbiotic intake on iron absorption was revealed in patients with type 2 diabetes mellitus, given the known association between metabolic disturbances and altered serum mineral levels. Synbiotic supplementation was shown to exert beneficial effects on iron absorption in both diabetic and non-diabetic individuals, with significant changes in serum iron bioavailability observed in both groups [54].

As previously discussed, oral iron supplementation can adversely affect the gut microbiota and promote intestinal inflammation. Increased luminal iron concentrations in the colon may reduce the abundance of beneficial bacteria such as *Bifidobacterium* and *Lactobacillus*, while promoting the growth of enterobacteria, including enteropathogenic *E. coli*. Therefore, combining oral iron therapy with probiotic supplementation may help mitigate these negative outcomes [55, 56].

A summary of selected studies evaluating the efficacy and safety of probiotic-based interventions in the correction of iron deficiency states is presented in the accompanying Table 1.

Table 1. Consumption of probiotics, prebiotics, and synbiotics in different types of iron deficiency and their effects on iron status

Type of iron deficiency	Probiotic strain/Prebiotic type	Reported effect
Impaired iron absorption	*Lactobacillus plantarum* FS2	↑ iron bioavailability by 128–372% [57]
Low iron bioavailability	*Bifidobacterium bifidum*, *B. longum*	↑ iron absorption [41]
IDA	*L. plantarum* 299v	↑ iron absorption [58, 59]
IDA	*Streptococcus thermophilus*	↑ iron uptake and utilization (improved hemoglobin, serum iron, total iron-binding capacity, ferritin) [60]
IDA	*L. fermentum*	Delivers iron nanoparticles to enterocytes, ensuring adequate iron uptake [61]
IDA	*L. acidophilus*	↑ serum ferritin and ↑ iron absorption [62]
IDA	*L. plantarum* 299v + iron + vitamin C	↑ blood iron levels [63]
IDA	*L. plantarum* Dad 13	No difference in iron status or gut microbiota profile [49]
Iron metabolism disorders associated with obesity	Multistrain probiotic (*B. bifidum* W23, *B. lactis* W51/W52, *L. acidophilus* W37, *L. brevis* W63, etc.)	May affect iron metabolism in postmenopausal women with obesity; further research is required [51]
Menorrhagia-related anemia	*L. plantarum* 299v + iron	↑ iron absorption [64]
IDA	GOS + inulin	Improved immune function in iron-deficient women [65]
IDA	FOS and GOS	↑ iron bioavailability [66]
IDA	Inulin	↑ iron sulfate bioavailability; ↓ calcium absorption [67]
IDA	GOS	↑ iron absorption [68]
IDA	Inulin + oligofructose	↑ DMT1 expression in the cecum, ↓ ferroportin expression in the duodenum, supports intestinal iron regulation [69]

Table 1. Consumption of probiotics, prebiotics, and synbiotics in different types of iron deficiency and their effects on iron status (*continued*)

Type of iron deficiency	Probiotic strain/Prebiotic type	Reported effect
Celiac disease-associated anemia	Inulin enriched with oligofructose	↓ serum hepcidin; ↑ iron absorption [70]
IDA	*B. lactis* HN019 + oligosaccharides	↓ risk of anemia and iron deficiency [71]
IDA	*B. bifidum*, *B. longum* + GOS	↑ iron absorption [42]

+: and; ↑: increase; ↓: decrease; DMT1: divalent metal transporter 1; FOS: fructooligosaccharides; GOS: galactooligosaccharides; IDA: iron deficiency anemia

As can be seen from Table 1, most studies show a positive effect of probiotic strains and prebiotics on iron metabolism. We can see that probiotics generally improve iron status by restoring disorders of the intestinal microbiota, which improves the absorption, bioavailability, and assimilation of iron. A large number of papers are devoted to the strain *L. plantarum* 299v. Perhaps, as a result of further research, data will be obtained that will allow the introduction of this strain, or other probiotic strains, into the treatment regimens of patients with impaired iron metabolism.

Conclusions

Both iron deficiency and iron overload in the gut during therapeutic interventions can negatively affect the composition and function of the intestinal microbiota. Conversely, beneficial members of the colonic microbiota play a key role in enhancing systemic iron absorption. Therefore, modulation of gut microbiota through targeted use of probiotics, prebiotics, and synbiotics represents a promising strategy in the comprehensive management of iron deficiency disorders. These interventions not only support microbiota restoration and reduction of intestinal inflammation, but may also offer novel therapeutic avenues for iron imbalance correction. It is essential to study the ability of probiotics to act as iron transporters, convert iron into an accessible form, or create metabolites that indirectly increase iron content and absorption in the intestine.

While a growing body of evidence supports the efficacy of probiotic-based interventions in correcting iron deficiency, additional well-controlled, large-scale clinical trials are necessary to conclusively validate the beneficial effects of probiotics, prebiotics, and synbiotics in this context.

Abbreviations

DMT1: divalent metal transporter 1

IBDs: inflammatory bowel diseases

IDA: iron deficiency anemia

Irp2: iron regulatory protein 2

SCFA: short-chain fatty acid

Declarations

Author contributions

NB: Conceptualization, Investigation, Writing—original draft. YU and VN: Writing—review & editing, Validation, Supervision. All authors read and approved the submitted version.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publication

Not applicable.

Availability of data and materials

Not applicable.

Funding

Not applicable.

Publisher's note

References

1. Khalilova N, Trapeznikova A, Shestakova M. Iron deficiency anemia in the structure of chronic diseases (literature review). Child Med North West. 2023;11:68–75. [DOI]
2. Boccio JR, Iyengar V. Iron deficiency: causes, consequences, and strategies to overcome this nutritional problem. Biol Trace Elem Res. 2003;94:1–32. [DOI] [PubMed]
3. Sornjai W, Long FNV, Pion N, Pasquer A, Saurin J, Marcel V, et al. Iron and hepcidin mediate human colorectal cancer cell growth. Chem Biol Interact. 2020;319:109021. [DOI] [PubMed]
4. Nadej EV, Nechaeva GI. Iron deficiency. High-risk group in general clinical practice. Lechashchij Vrach. 2014;7:26–31. Russian.
5. Bulatova EM, Bogdanova NM, Gabrusskaya TV. Iron deficiency and its negative impact on the development of young children. Dietary possibilities of postnatal correction of iron deficiency. Pediatriya Consilium Med. 2013;2:20–5. Russian.
6. Samson KLI, Fischer JAJ, Roche ML. Iron Status, Anemia, and Iron Interventions and Their Associations with Cognitive and Academic Performance in Adolescents: A Systematic Review. Nutrients. 2022;14:224. [DOI] [PubMed] [PMC]
7. Forth W, Rummel W. Iron absorption. Physiol Rev. 1973;53:724–92. [DOI] [PubMed]
8. Wollenberg P, Rummel W. Dependence of intestinal iron absorption on the valency state of iron. Naunyn Schmiedebergs Arch Pharmacol. 1987;336:578–82. [DOI] [PubMed]
9. Dietzfelbinger H. Bioavailability of bi- and trivalent oral iron preparations. Investigations of iron absorption by postabsorption serum iron concentrations curves. Arzneimittelforsch. 1987;37:107–12. [PubMed]
10. Cremonesi P, Acebron A, Raja KB, Simpson RJ. Iron absorption: biochemical and molecular insights into the importance of iron species for intestinal uptake. Pharmacol Toxicol. 2002;91:97–102. [DOI] [PubMed]
11. Xi R, Wang R, Wang Y, Xiang Z, Su Z, Cao Z, et al. Comparative analysis of the oral microbiota between iron-deficiency anaemia (IDA) patients and healthy individuals by high-throughput sequencing. BMC Oral Health. 2019;19:255. [DOI] [PubMed] [PMC]
12. Cherayil BJ, Ellenbogen S, Shanmugam NN. Iron and intestinal immunity. Curr Opin Gastroenterol. 2011;27:523–8. [DOI] [PubMed] [PMC]

13. Yilmaz B, Li H. Gut Microbiota and Iron: The Crucial Actors in Health and Disease. Pharm (Basel). 2018;11:98. [DOI] [PubMed] [PMC]
14. Weinberg ED. Iron availability and infection. Biochim Biophys Acta. 2009;1790:600–5. [DOI] [PubMed]
15. Buhnik-Rosenblau K, Moshe-Belizowski S, Danin-Poleg Y, Meyron-Holtz EG. Genetic modification of iron metabolism in mice affects the gut microbiota. Biometals. 2012;25:883–92. [DOI] [PubMed]
16. Simonyté SK, Domellöf M, Lagerqvist C, Hernell O, Lönnerdal B, Szymlek-Gay EA, et al. Administration of ferrous sulfate drops has significant effects on the gut microbiota of iron-sufficient infants: a randomised controlled study. Gut. 2019;68:2095–97. [DOI] [PubMed] [PMC]
17. Jaeggi T, Kortman GAM, Moretti D, Chassard C, Holding P, Dostal A, et al. Iron fortification adversely affects the gut microbiome, increases pathogen abundance and induces intestinal inflammation in Kenyan infants. Gut. 2015;64:731–42. [DOI] [PubMed]
18. Beasley FC, Marolda CL, Cheung J, Buac S, Heinrichs DE. Staphylococcus aureus transporters Hts, Sir, and Sst capture iron liberated from human transferrin by Staphyloferrin A, Staphyloferrin B, and catecholamine stress hormones, respectively, and contribute to virulence. Infect Immun. 2011;79: 2345–55. [DOI] [PubMed] [PMC]
19. Kim SR, Kim K, Lee SA, Kwon SO, Lee J, Keum N, et al. Effect of Red, Processed, and White Meat Consumption on the Risk of Gastric Cancer: An Overall and Dose¯Response Meta-Analysis. Nutrients. 2019;11:826. [DOI] [PubMed] [PMC]
20. Jahani-Sherafat S, Alebouyeh M, Moghim S, Ahmadi Amoli H, Ghasemian-Safaei H. Role of gut microbiota in the pathogenesis of colorectal cancer; a review article. Gastroenterol Hepatol Bed Bench. 2018;11:101–9. [PubMed] [PMC]
21. Louis P, Hold GL, Flint HJ. The gut microbiota, bacterial metabolites and colorectal cancer. Nat Rev Microbiol. 2014;12:661–72. [DOI] [PubMed]
22. Gulec S, Anderson GJ, Collins JF. Mechanistic and regulatory aspects of intestinal iron absorption. Am J Physiol Gastrointest Liver Physiol. 2014;307:G397–409. [DOI] [PubMed] [PMC]
23. Aslam MF, Frazer DM, Faria N, Bruggraber SFA, Wilkins SJ, Mirciov C, et al. Ferroportin mediates the intestinal absorption of iron from a nanoparticulate ferritin core mimetic in mice. FASEB J. 2014;28: 3671–8. [DOI] [PubMed] [PMC]
24. Carvalho L, Brait D, Vaz M, Lollo P, Morato P, Oesterreich S, et al. Partially Hydrolyzed Guar Gum Increases Ferroportin Expression in the Colon of Anemic Growing Rats. Nutrients. 2017;9:228. [DOI] [PubMed] [PMC]
25. Liu B, Pan X, Liu Z, Han M, Xu G, Dai X, et al. Fecal microbiota as a noninvasive biomarker to predict the tissue iron accumulation in intestine epithelial cells and liver. FASEB J. 2020;34:3006–20. [DOI] [PubMed]
26. Kalipatnapu S, Kuppuswamy S, Venugopal G, Kaliaperumal V, Ramadass B. Fecal total iron concentration is inversely associated with fecal Lactobacillus in preschool children. J Gastroenterol Hepatol. 2017;32:1475–79. [DOI] [PubMed]
27. Lee T, Clavel T, Smirnov K, Schmidt A, Lagkouvardos I, Walker A, et al. Oral versus intravenous iron replacement therapy distinctly alters the gut microbiota and metabolome in patients with IBD. Gut. 2017;66:863–71. [DOI] [PubMed] [PMC]
28. Martín R, Miquel S, Benevides L, Bridonneau C, Robert V, Hudault S, et al. Functional Characterization of Novel *Faecalibacterium prausnitzii* Strains Isolated from Healthy Volunteers: A Step Forward in the Use of *F. prausnitzii* as a Next-Generation Probiotic. Front Microbiol. 2017;8:1226. [DOI] [PubMed] [PMC]
29. Zhou L, Zhang M, Wang Y, Dorfman RG, Liu H, Yu T, et al. Faecalibacterium prausnitzii Produces Butyrate to Maintain Th17/Treg Balance and to Ameliorate Colorectal Colitis by Inhibiting Histone Deacetylase 1. Inflamm Bowel Dis. 2018;24:1926–40. [DOI] [PubMed]

30. Ze X, Duncan SH, Louis P, Flint HJ. Ruminococcus bromii is a keystone species for the degradation of resistant starch in the human colon. ISME J. 2012;6:1535–43. [DOI] [PubMed] [PMC]
31. Golonka RM, Xiao X, Abokor AA, Joe B, Vijay-Kumar M. Altered nutrient status reprograms host inflammation and metabolic health via gut microbiota. J Nutr Biochem. 2020;80:108360. [DOI] [PubMed] [PMC]
32. Buret AG, Motta J, Allain T, Ferraz J, Wallace JL. Pathobiont release from dysbiotic gut microbiota biofilms in intestinal inflammatory diseases: a role for iron? J Biomed Sci. 2019;26:1. [DOI] [PubMed] [PMC]
33. Dostal A, Chassard C, Hilty FM, Zimmermann MB, Jaeggi T, Rossi S, et al. Iron depletion and repletion with ferrous sulfate or electrolytic iron modifies the composition and metabolic activity of the gut microbiota in rats. J Nutr. 2012;142:271–7. [DOI] [PubMed] [PMC]
34. Dostal A, Baumgartner J, Riesen N, Chassard C, Smuts CM, Zimmermann MB, et al. Effects of iron supplementation on dominant bacterial groups in the gut, faecal SCFA and gut inflammation: a randomised, placebo-controlled intervention trial in South African children. Br J Nutr. 2014;112: 547–56. [DOI] [PubMed]
35. Loveikyte R, Bourgonje AR, van Goor H, Dijkstra G, van der Meulen-de Jong AE. The effect of iron therapy on oxidative stress and intestinal microbiota in inflammatory bowel diseases: A review on the conundrum. Redox Biol. 2023;68:102950. [DOI] [PubMed] [PMC]
36. Wilson AS, Koller KR, Ramaboli MC, Nesengani LT, Ocvirk S, Chen C, et al. Diet and the Human Gut Microbiome: An International Review. Dig Dis Sci. 2020;65:723–40. [DOI] [PubMed] [PMC]
37. Collins JF, Flores SRL, Wang X, Anderson GJ. Mechanisms and Regulation of Intestinal Iron Transport. In: Said HM, editor. Physiol Gastrointest Tract. 6th ed. San Diego: Academic Press; 2018. pp. 1451–83. [DOI]
38. Balamurugan R, Mary RR, Chittaranjan S, Jancy H, Devi RS, Ramakrishna BS. Low levels of faecal lactobacilli in women with iron-deficiency anaemia in south India. Br J Nutr. 2010;104:931–4. [DOI] [PubMed]
39. Vonderheid SC, Tussing-Humphreys L, Park C, Pauls H, Hemphill NO, LaBomascus B, et al. A Systematic Review and Meta-Analysis on the Effects of Probiotic Species on Iron Absorption and Iron Status. Nutrients. 2019;11:2938. [DOI] [PubMed] [PMC]
40. González A, Gálvez N, Martín J, Reyes F, Pérez-Victoria I, Dominguez-Vera JM. Identification of the key excreted molecule by Lactobacillus fermentum related to host iron absorption. Food Chem. 2017;228: 374–80. [DOI] [PubMed]
41. Pérez-Conesa D, López G, Ros G. Effect of Probiotic, Prebiotic and Synbiotic Follow-up Infant Formulas on Iron Bioavailability in Rats. Food Sci Technol Int. 2007;13:69–77. [DOI]
42. Goddard AF, James MW, McIntyre AS, Scott BB; British Society of Gastroenterology. Guidelines for the management of iron deficiency anaemia. Gut. 2011;60:1309–16. [DOI] [PubMed]
43. Miller JL. Iron deficiency anemia: a common and curable disease. Cold Spring Harb Perspect Med. 2013;3:a011866. [DOI] [PubMed] [PMC]
44. Constante M, Fragoso G, Calvé A, Samba-Mondonga M, Santos MM. Dietary Heme Induces Gut Dysbiosis, Aggravates Colitis, and Potentiates the Development of Adenomas in Mice. Front Microbiol. 2017;8:1809. [DOI] [PubMed] [PMC]
45. Cheng X, Guan L, Muskat MN, Cao C, Guan B. Effects of Ejiao peptide-iron chelates on intestinal inflammation and gut microbiota in iron deficiency anemic mice. Food Funct. 2021;12:10887–902. [DOI] [PubMed]
46. Turdieva S, Makhkamova GT. The role of Helicobacter pylori in the development of iron defi ciency anaemia in children. Exp Clin Gastroenterol. 2023;209:126–33. [DOI]
47. Ghibaudo F, Gerbino E, Copello GJ, Orto VCD, Gómez-Zavaglia A. Pectin-decorated magnetite nanoparticles as both iron delivery systems and protective matrices for probiotic bacteria. Colloids Surf B Biointerfaces. 2019;180:193–201. [DOI] [PubMed]

48. Pitarresi G, Tripodo G, Cavallaro G, Palumbo FS, Giammona G. Inulin-iron complexes: a potential treatment of iron deficiency anaemia. Eur J Pharm Biopharm. 2008;68:267–76. [DOI] [PubMed]
49. Helmyati S, Rahayu ES, Kandarina BJI, Juffrie M. No Difference between Iron Supplementation Only and Iron Supplementation with Synbiotic Fermented Milk on Iron Status, Growth, and Gut Microbiota Profile in Elementary School Children with Iron Deficiency. Curr Nutr Food Sci. 2020;16:220–7. [DOI]
50. Rosen GM, Morrissette S, Larson A, Stading P, Griffin KH, Barnes TL. Use of a Probiotic to Enhance Iron Absorption in a Randomized Trial of Pediatric Patients Presenting with Iron Deficiency. J Pediatr. 2019;207:192–7. [DOI] [PubMed]
51. Skrypnik K, Bogdański P, Schmidt M, Suliburska J. The Effect of Multispecies Probiotic Supplementation on Iron Status in Rats. Biol Trace Elem Res. 2019;192:234–43. [DOI] [PubMed] [PMC]
52. Rusu IG, Suharoschi R, Vodnar DC, Pop CR, Socaci SA, Vulturar R, et al. Iron Supplementation Influence on the Gut Microbiota and Probiotic Intake Effect in Iron Deficiency-A Literature-Based Review. Nutrients. 2020;12:1993. [DOI] [PubMed] [PMC]
53. Maawia K, Iqbal S, Qamar TR, Rafiq P, Ullah A, Ahmad M. Production of impure prebiotic galacto-oligosaccharides and their effect on calcium, magnesium, iron and zinc absorption in Sprague-Dawley rats. Pharma Nutr. 2016;4:154–60. [DOI]
54. Asemi Z, Aarabi MH, Hajijafari M, Alizadeh S, Razzaghi R, Mazoochi M, et al. Effects of Synbiotic Food Consumption on Serum Minerals, Liver Enzymes, and Blood Pressure in Patients with Type 2 Diabetes: A Double-blind Randomized Cross-over Controlled Clinical Trial. Int J Prev Med. 2017;8:43. [DOI] [PubMed] [PMC]
55. Paganini D, Zimmermann MB. The effects of iron fortification and supplementation on the gut microbiome and diarrhea in infants and children: a review. Am J Clin Nutr. 2017;106:1688S–93S. [DOI] [PubMed] [PMC]
56. Karpeeva YS, Novikova VP, Khavkin AI, Kovtun TA, Makarkin DV, Fedotova OB. Microbiota and human diseases: dietary correction. Ros Vestn Perinatol I Pediatr. 2020;65:116–25. [DOI]
57. Adeyanju AA, Kruger J, Taylor JR, Duodu KG. Effects of different souring methods on the protein quality and iron and zinc bioaccessibilities of non-alcoholic beverages from sorghum and amaranth. Int J Food Sci Technol. 2019;54:798–809. [DOI]
58. Adiki SK, Perla CK, Saha G, Katakam P, Theendra V. Enhancement in Iron Absorption on Intake of Chemometrically Optimized Ratio of Probiotic Strain Lactobacillus plantarum 299v with Iron Supplement Pearl Millet. Biol Trace Elem Res. 2019;190:150–6. [DOI] [PubMed]
59. Hoppe M, Önning G, Berggren A, Hulthén L. Probiotic strain Lactobacillus plantarum 299v increases iron absorption from an iron-supplemented fruit drink: a double-isotope cross-over single-blind study in women of reproductive age. Br J Nutr. 2015;114:1195–202. [DOI] [PubMed] [PMC]
60. El-azeem ASA, Hegazy AM, Badawy IH, Ibrahim GA, El-Shafei K, El-Sayed HS, et al. Effectiveness of Functional Wheat-Fermented Milk Beverage against Tannic Acid Induced Anemia. Res J Pharm Biol Chem Sci. 2016;7:2622.
61. Garcés V, Rodríguez-Nogales A, González A, Gálvez N, Rodríguez-Cabezas ME, García-Martin ML, et al. Bacteria-Carried Iron Oxide Nanoparticles for Treatment of Anemia. Bioconjug Chem. 2018;29:1785–91. [DOI] [PubMed]
62. Khodaii Z, Zadeh MN, Kamali J, Natanzi MM. Enhanced iron absorption from lactic acid fermented bread (an in vivo/ex vivo study). Gene Rep. 2019;15:100389. [DOI]
63. Korčok DJ, Tršić-Milanović NA, Ivanović ND, Đorđević BI. Development of Probiotic Formulation for the Treatment of Iron Deficiency Anemia. Chem Pharm Bull (Tokyo). 2018;66:347–52. [DOI] [PubMed]
64. Hoppe M, Önning G, Hulthén L. Freeze-dried Lactobacillus plantarum 299v increases iron absorption in young females-Double isotope sequential single-blind studies in menstruating women. PLoS One. 2017;12:e0189141. [DOI] [PubMed] [PMC]

65. Rizwan Ahmad AM, Ahmed W, Iqbal S, Mushtaq MH, Anis RA. Iron and prebiotic fortified flour improves the immune function of iron deficient women of childbearing age. Pak J Pharm Sci. 2020;33:253–61. [PubMed]
66. Christides T, Ganis JC, Sharp PA. In vitro assessment of iron availability from commercial Young Child Formulae supplemented with prebiotics. Eur J Nutr. 2018;57:669–78. [DOI] [PubMed] [PMC]
67. Dabour N, Dyab N, Kheadr E. Iron fortification of reduced-fat bioyoghurt containing either short-or long-chain inulin. Int J Dairy Technol. 2019;72:229–39. [DOI]
68. Laparra JM, Díez-Municio M, Herrero M, Moreno FJ. Structural differences of prebiotic oligosaccharides influence their capability to enhance iron absorption in deficient rats. Food Funct. 2014;5:2430–7. [DOI] [PubMed]
69. Marciano R, Santamarina AB, de Santana AA, Silva Mde L, Amancio OM, do Nascimento CM, et al. Effects of prebiotic supplementation on the expression of proteins regulating iron absorption in anaemic growing rats. Br J Nutr. 2015;113:901–8. [DOI] [PubMed]
70. Feruś K, Drabińska N, Krupa-Kozak U, Jarocka-Cyrta E. A Randomized, Placebo-Controlled, Pilot Clinical Trial to Evaluate the Effect of Supplementation with Prebiotic Synergy 1 on Iron Homeostasis in Children and Adolescents with Celiac Disease Treated with a Gluten-Free Diet. Nutrients. 2018;10:1818. [DOI] [PubMed] [PMC]
71. Sazawal S, Dhingra U, Hiremath G, Sarkar A, Dhingra P, Dutta A, et al. Effects of Bifidobacterium lactis HN019 and prebiotic oligosaccharide added to milk on iron status, anemia, and growth among children 1 to 4 years old. J Pediatr Gastroenterol Nutr. 2010;51:341–6. [DOI] [PubMed]