

Effects of Iron Deficiency on Children's Neurodevelopment

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Abstract: This paper systematically reviews the impact of iron deficiency on children's neurodevelopment. Iron deficiency, a prevalent nutritional issue globally, especially among children, not only causes iron deficiency anemia but also significantly affects various aspects of children's neurodevelopment, including cognition, behavior, and sleep. This study synthesizes the pertinent literature, elucidates the mechanism by which iron influences the brain's structural integrity and neuronal function, as well as its effects on other bodily systems. It addresses the current research gap regarding long-term follow-up studies and proposes that future investigations should explore the impact of other elements on neurodevelopment. Furthermore, the study underscores the critical importance of iron supplementation during early pregnancy for the optimal growth and development of children.

Keywords: Iron Deficiency, Children, Neurodevelopment, Cognition, Behavior

1. Introduction

Iron deficiency is a major global public health concern, particularly affecting children, especially in developing countries [1,2]. Due to their special physiological characteristics, children have a high demand for iron, especially in infancy and early childhood when iron deficiency is prone to occur [2,3]. Iron deficiency not only leads to iron deficiency anemia but also has a profound impact on the nervous system, including cognitive and behavioral development and long-term learning ability [4,5]. Iron plays a crucial role in neurotransmitter synthesis, myelination, and brain energy metabolism [2,5]. Understanding the effects of iron deficiency on children's neurodevelopment is essential for formulating effective prevention and intervention measures. Therefore, this paper focuses on the impact of iron deficiency on children's neurodevelopment and its corresponding solutions. This study enhances the comprehension of the mechanisms underlying iron's role in children's neurodevelopment, thereby offering novel perspectives and a robust theoretical foundation for scientific inquiry within related disciplines. Through the investigation of effective interventions, it provides empirical support for public health policymakers, facilitating efforts to address childhood iron deficiency and thereby contributing to the global advancement of children's health standards.

2. Iron and neural development

2.1. The role of iron in neural development

During neural development, iron is involved in multiple key processes. It is an important component of cytochrome oxidase, which plays a key role in neuronal energy metabolism. Iron

deficiency affects neuronal differentiation and maturation, impairs neuronal function, disrupts the myelination process, inhibits neurotransmitter synthesis and function, and affects synapse formation and function [6-10]. Iron deficiency is associated with impaired myelination and the development of dendrites and axons. It interferes with iron accumulation and energy metabolism in glial cells, affects the synthesis of myelin lipid components and proteins, and reduces the production of myelin-forming cells in the central nervous system (CNS) by influencing the differentiation and maturation of oligodendrocytes, thereby impacting myelination formation [11].

2.2. Effects of iron deficiency at different stages

Fetal Period: Iron deficiency during the fetal period causes abnormal neuronal differentiation and migration, inhibits myelination, and reduces nerve signal transmission efficiency, leading to cognitive dysfunction, impaired motor function, and abnormal social behavior in infants after birth [12,13].

Infancy (0 - 24 months): This is a critical period for neurodevelopment. Growth factors (IGF-I/II) and their receptors in the CNS are involved in the proliferation, differentiation, and myelination of neural and glial cells, and BDNF is involved in dendrite formation and mediates oligodendrocyte differentiation and myelination. ID decreased the expression of IGFs in the CNS and BDNF in the hippocampus, affected the differentiation and maturation of oligodendrocytes and myelination, altered the IGF-mediated signaling pathway, and reduced neurogenesis in the brain, especially in the hippocampus [11]. Insufficient iron during this stage affects neuronal maturation and myelination, resulting in lagging cognitive and motor functions, memory loss, poor concentration, and emotional instability [10,14-17].

Early Childhood (2 - 6 years old): The short- and long-term changes associated with iron deficiency are related to the major dopamine pathways (mesolimbic, midbrain limbic, substantia nigra striata, tuberculous pituitary inflammation). Dopamine D2 receptor-associated signaling controls cognitive flexibility, and iron deficiency may lead to altered conversion capacity by affecting D2 receptor-dominated signaling in the frontal-striatal circuit [10,18].

School - age Period (ages 6 and up): Lack of iron intake can cause neurobehavioral problems like attention deficit hyperactivity disorder (ADHD), leading to poor academic performance, weakened social skills, and a decline in the quality of life [9,19,20].

2.3. Effects of iron deficiency on children's mental development

Cognitive Function: Adequate ferritin in cord blood is associated with better neurodevelopment in newborns. Iron is essential for neurotransmitter synthesis and myelin formation, and iron deficiency is a major cause of impaired cognitive function in children[5].

Behavioral Performance: Symptoms of inattention and hyperactivity in children may be related to neurotransmitter disorders caused by iron deficiency, which can also affect social interaction and learning abilities[4].

Exercise and Sleep: Studies have shown that iron deficiency - related sleep disorders in children, such as increased abnormal activities during sleep, may be due to insufficient iron in the body, causing daytime performance problems and hindering normal life. Iron supplementation can improve sleep movement symptoms in some children[4].

Effects of Iron Deficiency during Pregnancy on Children's Neurodevelopment: Pregnant women's iron nutritional management is effective in preventing iron deficiency in newborns and promoting their neurodevelopment. The neurodevelopmental scores of newborns of pregnant women who received comprehensive health management combined with iron protein succinate were significantly higher[21].

3. Solutions

3.1. Early screening and monitoring

Assessing iron nutritional indicators in infants and young children, especially during the high - risk period of 6 to 12 months, through early screening of iron nutritional status and serum iron level testing can detect iron deficiency in a timely manner. For example, we can use the colorimetric method of methemoglobin cyanide (HiCN) to measure hemoglobin concentration in young children [22].

3.2. Preventive iron supplementation

Under the guidance of doctors, implementing preventive iron supplementation plans for high - risk groups, such as breastfed infants who may lack iron through complementary feeding, can promote cerebral cortex development and overall infant development [9]. For example, providing LNS (lipid-based nutritional supplements) to both pregnant women and infants during pregnancy can be effective in reducing anemia and ID in infants [23].

3.3. Nutrition education and guidance

Popularizing knowledge about iron - rich foods, such as iron - fortified cereals, red meat, and beans, and emphasizing their importance in infant complementary foods. Providing personalized nutrition guidance through community health services families develop appropriate complementary food addition plans.

3.4. Timely drug treatment

For infants and young children diagnosed with iron deficiency anemia (IDA), following the principle of appropriate dosage to provide timely iron therapy. Long - term small - dose iron supplementation can effectively improve cognitive functions such as attention and reduce side effects [24]. Higher cognitive functions develop as a result of the interaction of genes and biological (including nutritional) and socio-environmental factors. Iron supplementation can be supplemented with other nutrients (e.g., folic acid, B12, zinc, etc.) in order to regulate the physical condition of infants [11].

3.5. Long - term follow - up and evaluation

Conducting long - term follow - up of infants and young children receiving iron therapy to evaluate the effects of iron supplementation on neurodevelopment, and regular psychological and behavioral assessments to adjust treatment plans in a timely manner [12].

4. Conclusion

The impact of iron deficiency on children's neurodevelopment is multifaceted, affecting cognition, behavior, and sleep, which significantly influences their living standards. Starting iron nutrition management from pregnancy to ensure adequate iron intake for children, preventing iron deficiency, and promoting healthy growth are crucial.

Future research should further explore the long - term effects and specific mechanisms of iron deficiency, considering the interaction of other nutrients and environmental factors, to provide a scientific basis for more effective intervention measures. Long - term follow - up studies can be carried out to explore the long - term impact on children's neurodevelopment, especially in

adulthood. An in-depth exploration is required to elucidate the specific role and mechanism of iron in neurotransmitter synthesis, myelination, and brain energy metabolism. Additionally, an evaluation of various intervention measures is necessary, with a particular focus on iron nutrition management during pregnancy and iron supplementation in children.

In future studies, we can further explore the interactions of iron deficiency with other nutrients, especially the joint effects with vitamin D and zinc on human development. In addition, we can also propose strategies for iron nutritional interventions for children in different socio-economic contexts.

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