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Zinc: A Critical Micronutrient for Children's Health

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Zinc is one of the most abundant micronutrients in the human body, found in all tissues and playing an important role in vital structural, regulatory, hormonal and catalytic functions. Zinc deficiency is a major public health problem that affects almost one fifth of the world's population, being more common in low-income countries, where diets are poor in zinc sources, impacting morbidity and mortality rates, especially among children under five years of age. This narrative review updates the state of the art on the subject, highlighting the importance of zinc for metabolism, its metabolic roles and absorption issues, the clinical repercussions of deficiency conditions among children and points out some actions that can be implemented to reduce the severity of the problem, like supplementation, fortification, and biofortification that are proposed to mitigate zinc deficiency.

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1. INTRODUCTION

Zinc is one of the most abundant trace elements in the human body and can be found in all tissues and body secretions, participating in several vital functions with regulatory, hormonal, structural and catalytic activities such as protein synthesis, gene transcription, cell proliferation and differentiation and immune functions, which makes this mineral of fundamental importance for human growth and development [1].

Approximately one fifth of the world's population is at risk for insufficient zinc intake, with prevalence rates ranging from 17% to 29% distributed across countries in Asia, Africa and Central America [2,3], which places this deficiency as one of the five most important factors associated with mortality in developing countries [4]. This risk is greater, due to insufficient intake, among children under five years of age [5] and in premature infants (due to the high metabolic demand required for growth, low absorptive capacity and higher fecal and urinary loss than in full-term infants [6,7]. Considering the importance of zinc for human health and the high prevalence of deficiency in several regions of the world, this article aimed to review the knowledge about this micronutrient, highlighting its metabolism, clinical characteristics of deficiency and solutions to reduce the impact on populations.

2. METHODS

This is a descriptive study, of the narrative literature review type, carried out with the objective of identifying bibliographic productions with greater emphasis on the subject, with the proposal of developing the subject through analysis and interpretation of the existing scientific literature, in a non-systematic way. The data for analysis were obtained independently by the authors, who carried out a comprehensive search on scientific research platforms, in a non-systematic way, selecting the articles considered important after reading the full texts.

3. REVIEW

3.1 Zinc Metabolism, Absorption and Bioavailability

It can be inferred that the metabolism of zinc, a trace element essential for human health, depends on the intake of foods rich in this mineral to meet all metabolic demands. The main dietary sources of zinc are beef, oysters, chicken, egg yolks, beans, lentils, nuts, peanuts, sesame seeds, chickpeas, pumpkin, oats and brown rice [8,9]. Breast milk is the main source of zinc during the first six months of life, offering amounts ranging from 2.5 mg/L at the end of the first month of life to 0.7 mg/L after 4 months of age, sufficient for infants in this age group [10]. It is clear that breastfeeding, which stands out for its many benefits, and appropriate choices from complementary feeding, contribute to maintaining adequate zinc levels in eutrophic children.

The processes of zinc absorption and excretion in the body must be known, since changes in any pathway can culminate in serious deficiencies. During the digestion process, dietary zinc is released as free Zn^{2+} ions capable of forming complexes with organic acids, amino acids and phosphates, being actively absorbed in the distal duodenum and proximal jejunum [11] and taken to the liver by portal circulation. Almost 70% of zinc is transported bound to albumin, being absorbed by peripheral tissues, mainly muscles and bones, and by the liver, which functions as a temporary zinc deposit that can be mobilized to the plasma when necessary [7,9]. The absorption capacity of zinc present in the diet varies between 20% and 40%, depending on its bioavailability, which is greater in foods of animal origin [9]. In general, the presence of animal protein in the diet leads to an increase in the bioavailability of ingested zinc. There are also intraluminal factors that are considered to facilitate zinc absorption, such as amino acids (histidine and methionine), phosphates, organic acids, and some prostaglandins [12,13]. On the other hand, milk casein is associated with a negative effect on zinc absorption [14]. Zinc absorption can also be impaired by other factors, mainly by dietary phytic acid, present in phytates (legumes, beans, nuts, rice, oats, wheat), lignin, fiber, oxalates, phosphates, with which zinc forms insoluble complexes, reducing its bioavailability, in addition to some minerals such as iron, copper, calcium, and cadmium [3,9]. The main route of zinc excretion is through the gastrointestinal tract. Up to 10% of circulating zinc is also excreted in the urine [7]. Other routes of zinc loss are skin, hair, and nails [13].

Regarding requirements, during the first six months of life, zinc needs are met by exclusive breastfeeding. From six months of age onwards, the child's diet must contain foods rich in zinc. The daily zinc intake recommendations for children, according to the Institute of Medicine [15], are presented in Table 1.

Table 1. Daily zinc requirements (mg/day) for children and adolescents, according to age group

age	need (mg/d)
≤ 6 months	2
7 - 12 months	3
1 - 3 years	3
4 - 8 years	5
9 - 13 years	8
Adapted from IOM	

The main factors related to zinc deficiency include inadequate intake, low bioavailability in the diet (a diet predominantly made up of vegetables), poor absorption and increased losses (kidney diseases, parasitic infections, diarrhea) [6]. Especially among low-income populations, inadequate dietary intake of zinc is the main factor responsible for this deficiency [16]. Zinc deficiency compromises several organic structures and tissues whose cells have high turnover, such as the skin, gastrointestinal tract, central nervous system, immune system, skeleton and reproductive system [8]. Furthermore, zinc is involved in the activities of growth hormones, gonadotropins, sex hormones, prolactin and the thyroid [17], which may also have their functions altered in situations of deficiency. In the oral cavity, zinc is found in saliva, dental plaque and hard dental tissues and contributes to the healthy formation of teeth, preventing the appearance of cavities, gingivitis, periodontal disease and halitosis [18].

3.2 Clinical Manifestations

The first clinically identified manifestation of zinc deficiency was acrodermatitis enteropathica, a severe congenital disease of autosomal recessive inheritance that occurs in childhood and is characterized by hyperpigmented skin lesions on the extremities, face and buttocks, alopecia, irritability, diarrhea and growth deficit [19]. However, zinc deficiency is associated with several clinical manifestations, such as loss of appetite, dysgeusia, difficulties in healing, brittle hair, alopecia, skin changes (periorificial erythematous, vesiculobullous and pustular) in areas of friction such as knees, ankles and elbows, nails with whitish spots and Beau's lines, irritability, growth and developmental delay, neurosensory and neuropsychiatric changes [4], and learning difficulties [5,6,7]. Because the initial symptoms are slow to appear and are not very specific, the diagnosis and treatment of zinc deficiency may be delayed, contributing to the worsening of the clinical picture [17,18]. When zinc deficiency occurs during pregnancy, there may be an increased risk of fetal malformations and intrauterine growth restriction [7,20]. Zinc is the most abundant trace element in the brain and plays a fundamental role in the development of the central nervous system, participating in neuromodulation, neurogenesis (proliferation, migration and differentiation of neurons), plasticity, synaptogenesis, memory and learning [5,9,21]. Although the brain is highly plastic in the first years of life, a lack of micronutrients, especially zinc and iron, can cause damage and sequelae. During the neonatal period, large amounts of zinc can be found in the cerebellum, which is the structure responsible for muscle tone, balance and motor skills that will be acquired by the child early in life [22].

There have been reports of associations between zinc deficiency in children and infectious diseases, specifically diarrhea and acute lower respiratory tract infections, which contribute to increased morbidity and mortality [16]. It is also worth noting that zinc deficiency can occur in situations of iron deficiency due to the presence of foods and dietary factors that interfere with the absorption of these nutrients. This association may enhance the role of iron in another major global public health problem, iron deficiency anemia [3,6].

To identify zinc deficiency the child's dietary history, nutritional status, geographic origin and risk factors such as prematurity, low birth weight, exclusive breastfeeding after six months of age and associated diseases (parasitic infections, malabsorption syndrome, etc.) must be taken into account, since plasma zinc levels may not reflect the total zinc status of the organism and sensitive or specific biomarkers are not always available [23].

3.3 Public Health Strategies

Actions to reduce deficiencies are essential and should be considered a priority. Public health strategies and policies to solve the problem of hidden hunger should consider the intake of a diet in sufficient quantity to meet energy needs, of high quality, containing meats, dairy products, fruits, vegetables, grains and an adequate proportion of omega 3 and 6 fatty acids [24].

Table 2. Strategies to reduce the prevalence of zinc deficiency

Strategy	Features
supplementation	Individualized action aimed at more vulnerable population groups, as a short-term strategy, which has a positive impact on reducing problems such as diarrhea, premature birth and lower respiratory tract infections [25,26]. Furthermore, among children, it is possible to observe the impact on weight gain and growth, contributing to the reduction of morbidity and mortality in this age group [2,3,7,16]. Preventive supplementation can reduce the occurrence, duration and severity of episodes of diarrhea and respiratory infections [17] among children from populations with lower socioeconomic status.
fortification	It is a proven and safe strategy that involves adding nutrients during processing to foods consumed regionally and regularly, such as flour, rice, wheat, corn, sugar, milk and milk formulas, and bread [2,3,8,27]. This practice respects the eating habits of the population and adds nutritional value to the products, and is recommended by the World Health Organization [28,29,30].
biofortification	Its purpose is to increase zinc levels in edible vegetables during the growth period, using agronomic techniques (fertilizers to enhance the absorption of micronutrients by plants and accumulation in edible parts) and genetic improvement (repeated crossings of plants of the same species until more nutritious crops with a higher micronutrient content are obtained [31,32,33].

Increasing intake and reducing global zinc deficiency, especially among the most vulnerable groups, requires the adoption of strategies that combine interventions such as supplementation, fortification and improvements in agricultural production areas [2]. Specifically regarding the intake of micronutrients in general, and zinc in particular, some strategies can be adopted, alone or in combination, as shown in Table 2.

For the pediatric age group, some authors have suggested using solutions containing zinc that should be offered 1 hour before and 2 to 3 hours after meals. For better absorption, it should be avoided ingesting it together with supplements containing iron, copper or phosphorus. Dosages and administration time vary according to the objectives of the supplementation program [34,35,36].

4. CONCLUSION

Zinc deficiency is one of the most prevalent forms of micronutrient malnutrition and has a major impact on human health. This study allowed the authors to review the epidemiology, clinical manifestations and importance of preventing zinc deficiency in childhood. Thus, this publication brings to the fore a topic recognized by the World Health Organization as a serious global public health problem that requires urgent adoption of effective public policies.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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