The Impact of Malnutrition on Cognitive Development in Children

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Abstract

Malnourished children suffer from cognitive development defects that lead to long-lasting effects on their academic performance, emotional well-being, and socioeconomic future. This chapter looks at the global prevalence of malnutrition and its types, such as undernutrition, overnutrition, micronutrient deficiencies, and protein-energy malnutrition. Major causes of malnutrition, including poverty, food insecurity, inadequate dietary intake, maternal health issues, and dietary shifts brought about by urbanization, are also described in this chapter. The critical periods in the development of the brain, including prenatal, infancy, and adolescence, are discussed with an emphasis on the influence of malnutrition on the development of brain structures, neurotransmitters, and cognitive abilities. Short-term effects such as deficits in memory, attention, and problem-solving are discussed along with the long-term effects on academic outcomes, emotional stability, and the cycle of poverty. The chapter describes interventions, including nutrition programs, health care initiatives, and policy-level actions, and the role of international organizations in combating malnutrition. The chapter concludes by addressing research gaps and future directions, emphasizing the need for innovative strategies to combat malnutrition and promote optimal cognitive development in children worldwide.

Keywords: Malnutrition, Cognitive development, Child health, Academic performance, Poverty

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Introduction

Malnutrition is a state of imbalance in the intake of essential nutrients, either deficient, excessive, or inadequately used. It can be undernutrition (too little food) or overnutrition (too much food). This imbalance greatly affects the body, leading to decreased immunity, poor growth, or serious chronic disease (Cleveland Clinic, 2022). Children's cognitive development involves the progressive development of skills and abilities related to thinking, reasoning, memory, language, and problem-solving. It includes the development of the mental processes that enable children to make sense of and interact with the world around them based on biological maturation and environmental experiences. According to Jean Piaget's theory, stages of cognitive development such as sensorimotor, preoperational, concrete operational, and formal operational, indicate the ways according to which children's thinking develops from its basic sensory and motor activities to complex abstract reasoning (Piaget, 1952; Siegler et al., 2019).

1.1 Global Prevalence of Malnutrition in Children

Malnutrition among children is a global health problem to a very severe extent, especially in low and middle-income countries. The latest estimate is that 149 million children under age five are stunted (too short for their age), 45 million are wasted (too thin for their height), and 38.9 million are overweight. Typically, these forms of malnutrition include both overnutrition and undernutrition, and these result in impaired physical and cognitive development, the overall health of children, and health risks and challenges for the rest of their lives (WHO, 2021).

Regional variation in the global burden of malnutrition is quite significant. The highest rates of child undernutrition in the world are found in South Asia and sub-Saharan Africa, where about a third of children suffer from stunting. On the contrary, in North America, Europe, and some parts of the Middle East and Asia, there has been considerable increase in overweight and obesity in children arising out of rapid urbanization, changes in dietary habits, and reductions in physical activity (UNICEF, WHO & World Bank, 2021).

Malnutrition is also a significant public health issue in Palestine and Gaza. According to UNICEF, 31 percent (1 in 3) of children under two years of age in Northern Gaza were acutely malnourished in 2024 (UNICEF, 2024). To reduce child malnutrition, food security, access to health care, support for breastfeeding and complementary feeding, and nutrition-sensitive policies need to be promoted (UNICEF, 2020).

1.2 Association between Malnutrition and Cognitive Development

Malnutrition significantly impacts cognitive development, especially during critical growth periods in early childhood. Poor nutrition, including a lack of protein, energy, and specific micronutrients such as iron, iodine, and zinc, can damage brain development and the child's cognitive function. Children who are malnourished have slower motor skills, short attention spans, memory problems, and poor academic performance. Therefore, proper nutrition is vital for neurogenesis, synaptogenesis, and myelination, all of which are important contributors to brain development (Prado & Dewey, 2014a; Black et al., 2017). For example, chronic malnutrition, such as stunting, has been associated with long-term cognitive deficits and lower productivity in adulthood. Similarly, iron deficiency anemia impairs neurotransmitter function and myelin synthesis, therefore slowing cognitive development (Grantham-McGregor et al., 2007a).

2 Types and Causes of Malnutrition

Malnutrition is mainly divided into undernutrition and overnutrition. It can also occur because of an imbalance of macronutrients (including proteins, carbohydrates, and fats) or micronutrients (vitamins and minerals).

2.1 Types of Malnutrition

It can be further divided into the following types:

2.1.1 Undernutrition

It includes conditions such as wasting, stunting, and underweight.

Wasting: It is a form of acute malnutrition and occurs due to food shortages. It is manifested by low weight for height.

Stunting: It is caused by chronic undernutrition and is shown by low height for age.

Underweight: The combination of wasting and stunting is named underweight and is reflected by low weight for age.

2.1.2 Micronutrient Deficiencies

It is a deficiency of certain important vitamins and minerals such as iron, iodine, vitamin A, zinc, etc. Deficiency of these micronutrients can also lead to anemia or poor immunity.

2.1.3 Overnutrition

Excess calorie intake leads to overnutrition. People with overnutrition become overweight or obese and suffer from nutrition-related noncommunicable diseases (Cleveland Clinic, 2022).

2.1.4 Protein-Energy Malnutrition

Protein–energy malnutrition is a type of undernutrition that occurs from poor intake of calories and protein, often with subsequent infections and sickness. It primarily affects children under five years of age in low and middle-income countries and can result in significant morbidity and mortality. PEM manifests in two major forms: kwashiorkor, characterized by edema and fatty liver, and marasmus, marked by extreme wasting due to chronic energy deficiency (Victora et al., 2021).

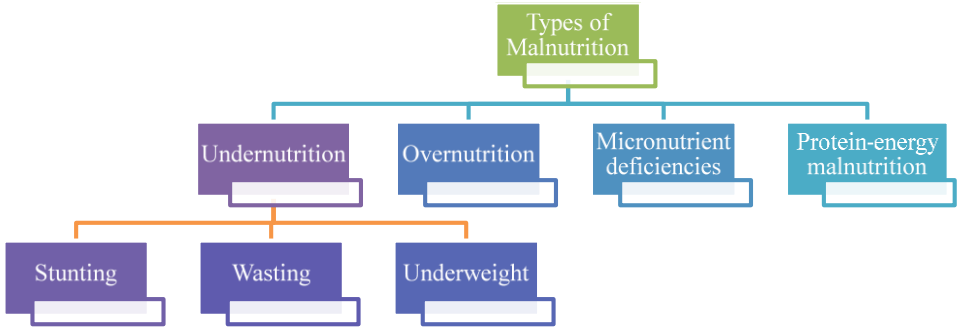

Fig. 1: Types of Malnutrition
Note: Created by Fahmida Channa, adapted from Cleveland Clinic (2022).

2.2 Causes of Malnutrition

Malnutrition in children typically results from a combination of dietary, socioeconomic, health, and environmental factors.

2.2.1 Poverty and Food Insecurity

Poverty favors malnutrition because it limits the affordability with which families can obtain or even access proper diets. On the other hand, food insecurity means the lack of timely access to appropriate amounts of adequate and healthy foods mostly impacts low-income families, therefore raising the likelihood of the development of malnutrition in children (World Bank, 2020).

2.2.2 Inadequate Dietary Intake

Insufficient or inadequate quantity and quality of the diet is one of the leading causes of malnutrition because children lack the calories, protein, and micronutrients to support their development. It may be because many individuals have little to no access to different healthy foods, especially in low-income families where diets typically consist of little to no protein or micronutrient-rich foods (Black et al., 2013).

2.2.3 Poor Maternal Health and Nutrition

Maternal nutrition and health during pregnancy also play a crucial role in ascertaining the nutritional status as well as total health of a child in childhood. Child undernutrition often originates from the time when the baby is in the womb; poor maternal nourishment and illness during the pregnancy significantly contribute to fetal growth retardation, low birth mass, and developmental issues (Black et al., 2013).

2.2.4 Infectious Diseases

The majority of malnutrition occurs due to conditions like diarrheal diseases, respiratory infections, and parasites such as intestinal worms (Asrar et al., 2023). These conditions may also lower appetite, raise nutrient loss, and lower nutrient absorption in a cycle whereby infected children will be more vulnerable to other infections, which will affect their nutritional status (UNICEF, 2020).

2.2.5 Urbanization and Dietary Shifts

Dietary transitions, especially for poor families, are significantly influenced by the process of rapid urbanization. Lack of fresh produce in most urban homes results in 'food deserts or access to cheaper energy-dense and micronutrient-poor diets. This transformation has led to a transition from undernutrition to childhood obesity, especially in an urban low-income setting (Popkin, 2015).

2.2.6 High-calorie, Low-nutrient Diets

It includes high-calorie, low-nutrient diets that prevail over other types of diets and might include too much sugar, fat, and processed foods. This dietary pattern is most evident in the urban setting and is slowly emerging in the low-middle-income/upper-lower-income countries as these transmute into the mid-income category (Popkin, 2015).

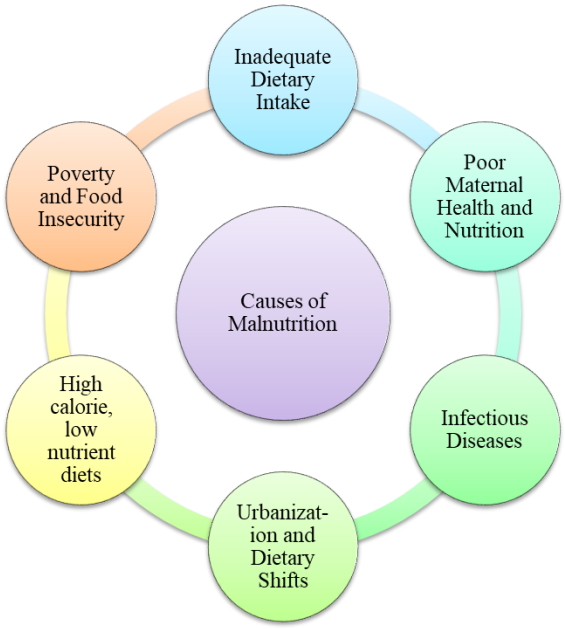

Fig. 2: Causes of Malnutrition; Note: Created by Fahmida Channa, adapted from Black (2013) and Popkin (2015).

3 Cognitive Development in Children

This development occurs in a series of stages, with distinct milestones that influence a child's ability to interact with the world around them.

3.1 Stages of Cognitive Development in Children

Cognitive development occurs in the following stages:

3.1.1 Sensorimotor Stage (Birth to 2 Years)

The sensorimotor stage, according to Jean Piaget, is the first stage of cognitive development in infants. Children at this stage learn object permanence— that objects continue to be around even when we can't see or hear them. It is foundational to later reasoning and problem-solving (Piaget, 1952; Berk, 2013).

3.1.2 Preoperational Stage (2 to 7 Years)

Children in the preoperational stage of development play symbolically and communicate with language. However, they are still egocentric or cannot think about other people's points of view except their own (Piaget, 1952). Cognitive abilities like classification and conservation start appearing in children, but not all at once i.e. they focus on one part of a situation at a time (Berk, 2013).

3.1.3 Concrete Operational Stage (7 to 11 Years)

It is a stage where logical thinking begins. It allows children to perform operations with concrete objects and understand the concepts of conservation, classification, and reversibility. However, their thinking is stuck on the object, the action, and concrete instantiations. Although emerging at this stage, abstract thinking seems not fully developed (Piaget, 1952).

3.1.4Formal Operational Stage (11 Years and beyond)

Children start to think abstractly, logically, and systematically in this stage. For example, they can reason hypothetically deductively, solve problems less haphazardly, and imagine what is possible beyond the immediate experience (Piaget, 1952). It is an essential part of moving from childhood to adolescence and being ready for adulthood. This stage sets the base for future reasoning capabilities.

3.2 Critical Periods of brain Development Affected by Malnutrition

Brain development is a process that has many stages and some really critical periods early in life that are most sensitive to the nutritional influences that it involves.

3.2.1Prenatal Period (Conception to Birth)

The first critical period of brain development takes place throughout pregnancy mainly in the first 1,000 days of maturation from conception to the age of two. Maternal malnutrition, in particular of micronutrients such as folate, iodine, and iron, has been shown to be capable of causing both structural and brain cognitive impairments. One specific example is that iodine deficiency during pregnancy is related to impairing brain development and intellectual disability (Delange, 2000).

3.2.2 Infancy and Early Childhood (0–3 Years)

The postnatal period (mainly the first 3 years) is another critical window for brain development. This is a time associated with rapid synaptogenesis and the formation of new synaptic connections. Malnutrition (lack of protein, fat, and essential micronutrients) at this stage can decrease synaptic connections between neurons, and hamper cognitive and motor development. For example, protein energy malnutrition results in stunting and delays in motor development, and vitamin A deficiency has been shown to delay cognitive growth (Grantham-McGregor et al., 2007b).

3.2.3 School-Age and Adolescence (6–18 Years)

The brain does not stop developing throughout adolescence. This period is not as critical as early childhood. However, malnutrition still damages cognitive function at this stage — specifically, attention and memory. In this phase, the brain is also susceptible to deficiencies of vitamins such as vitamin B12, vitamin D, and iron. These deficiencies can influence brain function and academic performance (Dewey & Adu-Afarwuah, 2008).

3.3 Importance of Nutrition for Cognitive Development in Early Childhood

Nutrition is important for the following reasons:

3.3.1Formation and Growth of Brain Structures

Proteins and omega-3 fatty acids are important for nerve & synapse growth that help brain cells work properly. Omega 3 fatty acids feed the brain wall and support neuronal communication so enabling the learning process. Nutrients like vitamins A, D, and folic acid are also required for cellular growth and differentiation necessary for neural pathways that allow learning and memory (Black, 2003; Georgieff, 2007).

3.3.2 Development of Cognitive Abilities

A deficiency of micronutrients such as iron, iodine, and zinc affect a child's cognitive development. Iron is required for oxygen transport in the brain and is vital for myelination (formation of a myelin sheath, or outer covering around a nerve cell and its axon that insulates the axon of the nerve cell). Low iron levels can cause a deficiency in attention, memory, and executive function (Lozoff et al., 2006).

3.3.3 Neurotransmitter Function and Emotional Health

Serotonin and dopamine are neurotransmitters that control mood, behavior, and motivation. They are made from Vitamin B6, folate, or tryptophan. An imbalance of these neurotransmitters can lead to emotional regulation problems and may even predispose children to anxiety or depressive symptoms (Prado & Dewey, 2014b).

3.3.4 Role of Antioxidants in Brain Health

Antioxidants such as vitamins C and E guard the brain against oxidative stress that causes damage to neurons and interferes with cognitive function. Oxidative stress damages particularly in early childhood because it can create chronic inflammation with an impact on brain cell function and development (Gómez-Pinilla, 2008).

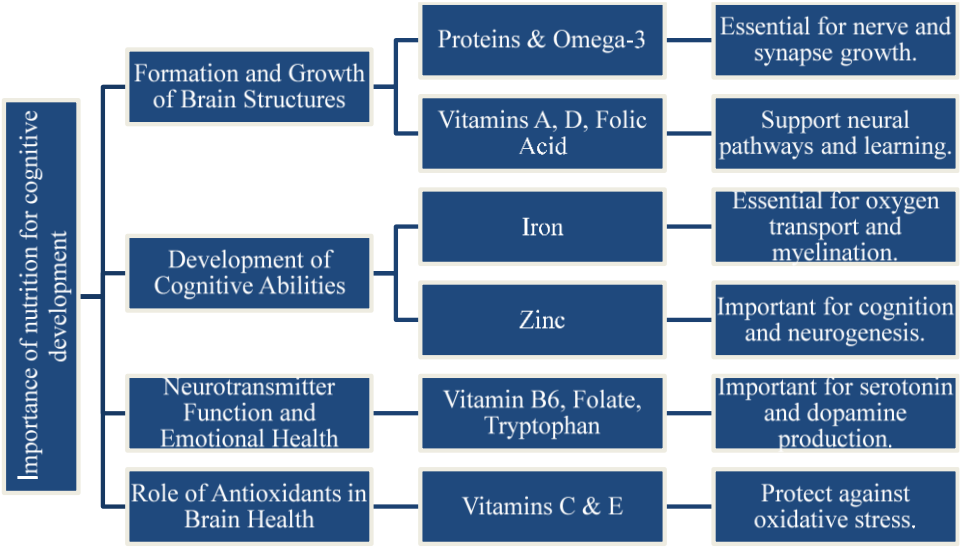

Fig. 3: Importance of nutrition for Cognitive development in early childhood; Note: Created by Fahmida Channa, adapted from Georgieff (2007), Gómez-Pinilla (2008), and Prado & Dewey (2014).

3.4 Key nutrients Essential for Brain Development

Protein, fatty acids, vitamins, and minerals are the nutrients vital for the brain in the initial stages of physical development.

3.4.1Proteins

Proteins are a source of amino acids required for the formation of neurotransmitters that help the brain's cells to exchange information. These neurotransmitters are important in memory, learning and even the comprehensive ability. Proteins also play a critical role in organizing the formation of head tissues. Healthy sources of protein include eggs, beans and nuts, fish and lean meats.

3.4.2 Omega-3 Fatty Acids

They are crucial for maintaining the membrane of brain cells and for the transmission of information across the membrane. They can reduce inflammation that may occur in and around the brain cells. These nutrients are helpful to increase memory as well as the ability to think. They are found in fatty fish such as salmon, sardines, and trout.

3.4.3 Vitamins and Minerals

B Vitamins (especially B12 and Folate) are important in the synthesis of neurotransmitters as well as the normal functioning of the nervous system.

3.4.4 Iron

Iron is required for oxygen transport in the brain and is important in myelination. Cognitive iron deficiency affects memory and attention. People with iron deficiency face difficulty in performing tasks such as reading, writing, and arithmetic.

3.4.5 Zinc and Iodine

Zinc is important for neurogenesis and iodine is used for synthesis of thyroid, which is associated with cognition.

3.4.6 Healthy Fats

These monounsaturated and polyunsaturated fats protect the structural integrity of the brain as well as facilitate its myelination, thus helping the brain to work efficiently. They are found in olive oil, nuts, and avocados.

3.4.7 Antioxidants

Antioxidants defend the brain from additional oxidization that could compromise its cells and retard brain growth. They are present in berries.

Consumption of all these nutrients in the initial phases of life is vital for the provision of fundamental brain architecture, memory, learning, and emotional well-being (Pediatric Brain Foundation, 2023; Verywell Family, 2023).

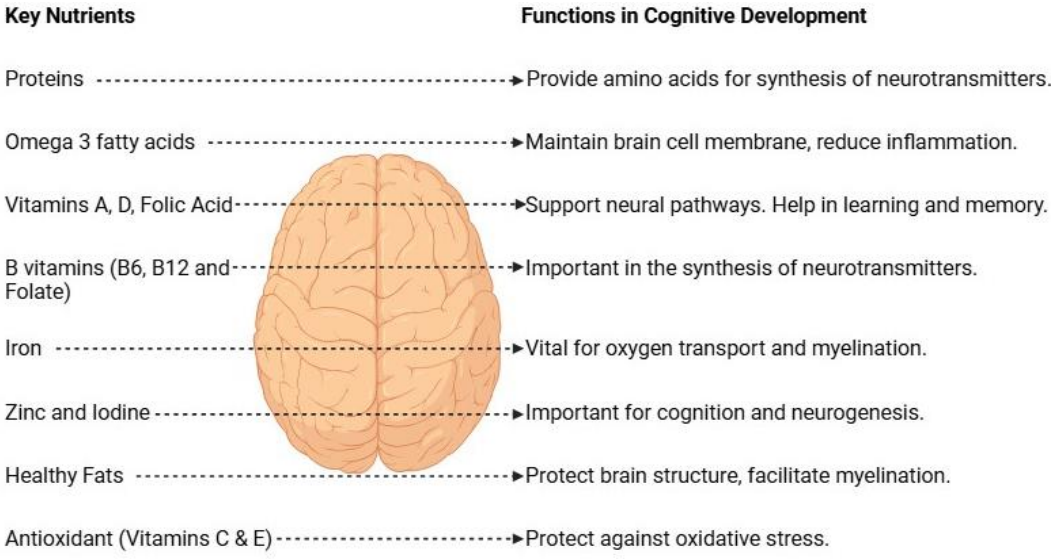

Fig. 4: Key nutrients and their role in Cognitive development; Note: Created by Fahmida Channa, adapted from Pediatric Brain Foundation (2023) and Verywell Family (2023).

4 Impacts of Malnutrition on Cognitive Development

Malnutrition has the following impacts on cognitive development in children:

4.1 Neurological impacts and Biochemical impacts of Nutrient deficiencies

Malnutrition during early childhood development causes severe neurological and biochemical outcomes in cognitive development.

4.1.1 Neurological Impacts

Lack of essential nutrients compromises brain integrity through altering neural connections, myelin sheath, and neurotransmitters. The most common nutrients associated with an impaired brain include iron, iodine, zinc, and vitamin B12. For instance, Iron deficiency anemia in early childhood leads to poor concentration, learning, and memory problems as this is important in the oxygenation of the brain cells and myelination of nerves. Likewise, a deficiency of iodine causes neurological impairment and developmental disability of the Thyroid hormone that is vital in the growth of the brain. Lack of zinc and vitamin B12 can also cause a decline in learning ability because of its impact on the brain's plasticity and the synthesis of critical brain neurotransmitters such as serotonin and dopamine (Prado & Dewey, 2014c; Suryawan et al., 2021).

4.1.2 Biochemical Impacts

On a biochemical level, these deficiencies affect some of the most important metabolic processes in the body. For instance, insufficient B vitamins, particularly folate and B12, compromise the DNA synthesis and cell division on which children's brain development beyond infancy depends. Further, shortages in omega-3 fatty acids decrease the stability of neural membranes which in turn decreases the rate of synaptic transmission and hampers the ability of the brain's nerve cells to communicate (Prado & Dewey, 2014c).

4.2 Short-term Impacts of Malnutrition (in infancy and early childhood)

Malnutrition has the following short-term impacts:

4.2.1Memory and Learning

Malnutrition has a profound impact on cognitive functions such as retention and recall, particularly in early childhood when the brain is undergoing critical development. Nutritional deficiencies in protein, iron, iodine, and omega-3 fatty acids impair neurogenesis, synaptic plasticity, and myelination, which are essential for memory and learning. Iron deficiency, for instance, disrupts neurotransmitter synthesis and myelin production, leading to reduced cognitive abilities (Lozoff et al., 2006).

The effect of malnutrition on memory and learning is quite alarming. In a study, animals were used to study the impact of malnutrition on the brain. Results of the study indicated slow reaction and struggle in memory tasks from animals. For example when these malnourished animals were tested in the "Morris water maze test", where they had to remember the platform to escape the water. They find it very hard to complete the task (Valadares et al., 2010).

4.2.2 Attention Deficits

Malnutrition in the early stages of life is linked to pro-longed attention problems. As observed, the people who were malnourished as infants often continued to have some serious issues in attention while they were in middle age, even if they received proper nutrition later on. Studies from the past have shown that children's malnutrition can lead to long-term attention difficulties regardless of high IQ and socioeconomic background (Galler et al., 2012).

4.2.3 Effects on Problem-solving and Decision-making

Malnutrition has been observed to cause a reduction of performance in executive functions that need decision-making and problem-solving skills. Long-term conditions of malnutrition in children showed a very low problem-solving and decision-making ability (Rivera-Oliveros et al., 2013). Malnutrition can also cause to slow down the cognitive development of children as it grows, as seen in stunted children who performed very badly in different tests of executive functions. They also showed less progress in working memory with time as compared to the well-nourished ones (Kar et al., 2008).

4.3 Long-term Impacts of Malnutrition

Long-term effects of malnutrition can be observed in educational and career achievements. Adults who had been severely malnourished as a child were not able to do well in school resulting in lower self-esteem in the later stages of their life, suggesting that malnutrition can significantly minimize educational and job success (Mwene-Batu et al., 2020).

4.3.1Academic performance

Malnutrition affects cognitive abilities making it harder to learn and process information. Research in Ethiopia showed that children who were underweight and stunted performed worse academically due to their diminished abilities to think and learn. (Zerga et al., 2022). Additionally, research in India also formulated that malnourished students often get lower grades due to the effects caused by poor nutrition (Verma, 2020). Another study in Pakistan showed that malnourished students were missing school more frequently due to illness leading to a further decline in their academic success (Shabbir et al., 2019).

4.3.2 Emotional and Behavioral Issues

Malnutrition also has a huge impact on emotional health. Malnourished children generally show behaviors like aggression and hyperactivity mainly due to the disruptions in the development of those parts of the brain that are responsible for emotional control (Liu & Raine, 2006). Research indicates that Children with malnourished backgrounds are more likely to show aggressive, and antisocial behaviors (Liu et al., 2004).

4.3.3 Socioeconomic Outcomes

Malnutrition in infant age can lead to reduced income in adulthood. A study in Barbados showed that the people who were malnourished at a lower age earned less than those who were well-nourished (Galler et al., 2012). Furthermore, malnourished people have long-term hospital stays with higher costs, accounting for other health and economic issues (Lim et al., 2012).

4.3.4 Cycle of Poverty and Malnutrition

Poverty is among the main causes of less access to nutritious food, leading to malnutrition. This low availability of nutrition makes economic struggles even harder by impacting mental as well as physical health as a result reducing the ability to do work and earn money (Siddiqui et al., 2020). Malnourished children have limited job potential when they grow up. It creates a cycle of malnutrition and poverty which continue from one generation to the next (Delisle, 2008).

5 Interventions and Policies to Address Malnutrition and Improve Cognitive Development

The following interventions could help to overcome malnutrition:

5.1 Nutritional Interventions

These include programs that enhance food availability and diversity, such as home gardening, fortification of staple foods (e.g., iodine in salt, iron in flour), and community meal programs (Jamil et al., 2023). Food fortification involves adding essential nutrients, such as iodine,

iron, and vitamin A, to commonly consumed foods like salt, flour, and cooking oil. Fortification has been a cost-effective approach for addressing micronutrient deficiencies on a broad scale. Food fortification is a proven method to combat micronutrient deficiencies on a large scale (Mannar & Hurrell, 2018).

5.2 Emergency Food Aid and Relief Programs

In areas affected by natural disasters, conflict, or other crises, emergency food aid provides immediate food assistance to prevent malnutrition and support recovery efforts. Organizations like the World Food Programme (WFP) play a significant role in providing emergency food supplies to vulnerable populations (World Food Programme, 2020).

5.3 Behavioral and Educational Interventions

These focus on raising awareness about healthy eating practices, breastfeeding, complementary feeding, and hygiene to optimize nutrient intake and absorption (UNICEF, 2021).

5.4 Healthcare-related Interventions

For effective nutritional rehabilitation, there is a critical need for early diagnosis and treatment of underlying health conditions that impair nutrient absorption, such as infections, diarrhea, and parasitic diseases (R. E. Black et al., 2013). In addition, the health care system should be strengthened for regular growth monitoring and timely interventions, preventing long-term developmental delays. Global-level initiatives like the Scaling Up Nutrition (SUN) Movement advocate for a sectoral approach to fight malnutrition by combining the efforts of governments, international organizations, and the private sector. It will help to accelerate efforts to tackle malnutrition on a large scale and create a supportive environment that will improve nutritional outcomes (SUN Movement, 2023).

5.5 Global Policy to Overcome Malnutrition

Universal health coverage, more effective agricultural policies, and sustainable food systems are critical for the long-term solutions of malnutrition (Global Nutrition Report, 2020). The nutritional interventions must meet local context through interventions that address cultural, economic, and environmental factors that contribute to malnutrition.

5.6 Role of International Organizations

The United Nations Children's Fund (UNICEF), World Food Programme (WFP), and the World Health Organization (WHO) work with governments and local organizations in the fight against malnutrition, particularly among children, pregnant women, and displaced populations. UNICEF implements programs such as Community Based Management of Acute Malnutrition (CMAM), providing therapeutic food and health services to children who are severely malnourished (UNICEF, 2023).

WFP provides emergency food assistance and food security initiatives to supports millions of people affected by crises annually. Their programs typically involve food and cash transfers, school feeding programs, and agricultural support for improved and long-term resilience. For example, the WFP provides food to around 90 million people in more than 80 countries, particularly nutritional support during emergencies and crisis situations (World Food Programme, 2023). On the other hand, WHO has a main role in monitoring global health standards and providing technical support to deal with malnutrition on a large scale (World Health Organization, 2023).

6 Research gaps and Future Directions to Overcome Malnutrition

A significant research gap is the lack of understanding of the social and environmental determinants of child malnutrition, particularly in rapidly changing global currents such as climate change, urbanization, and economic inequality (UNICEF, 2023).

Secondly, new nutrition interventions must be made more efficacious and scalable. Programs, including food fortification, micronutrient supplementation, and school feeding, have been demonstrated to improve nutritional outcomes but their long-term effectiveness in various settings is still uncertain. The scaling up of these interventions in resource-constrained environments requires research to assess their cost-effectiveness and sustainability as well as their cultural acceptability (FAO, 2022).

In addition, producing new integrated technologies for the fight against child malnutrition is an area of growing interest. Better outcomes of malnutrition programs can be achieved through advances in mobile health and digital platforms for nutrition education, monitoring, and data collection. However, more research is necessary to establish the extent to which digital interventions can complement older methods and to determine if digital methods have been an effective way to reach the most vulnerable populations (WHO, 2023).

Conclusion

Cognitive development in children is profoundly affected by malnutrition, especially around periods of significant brain growth. Immediate effects such as impaired memory, attention, and problem-solving skills and enduring impacts on learning, academic performance, emotional health, and socioeconomic outcomes, can occur due to malnutrition. Comprehensive strategies are needed to address malnutrition which include nutritional interventions, healthcare programs, and behavioral education. Nutritional support during the earliest period of child growth can help to break the cycle of poverty and malnutrition. It is also helpful in mitigating cognitive deficits. To ensure lasting improvements in the cognitive and total development of children, there is a need for collective efforts of governments, international organizations, and communities.

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