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Zinc Deficiency in Cognitive Development and Mental Health in children from Latin America

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Zinc

Zinc is a trace mineral needed for around 100 enzymes to carry out essential chemical reactions. Zinc is important in the creation of DNA, development of cells, protein production, healing of damaged tissue, and maintaining a healthy immune system. Due to the role it plays in cell production and growth, a sufficient amount of zinc is required during the stages of the rapid growth seen in child development, adolescence, and pregnancy (Roohani et al., 2013). Zinc's role in over 400 enzymatic reactions and presence in more than 2,000 proteins in the human body makes it necessary for more functions in the nervous system, gastrointestinal, and respiratory systems. It also plays a role in gene expression, protein synthesis, cell development, and replication (Pinzón-Rondón et al., 2019). Despite all the different important roles zinc plays in the functioning of the body, this mineral is not stored in the body and therefore requires a consistent intake of dietary sources that are high in zinc (Maxfield et al., 2021). Zinc deficiency can be found in many food sources including meats, seafood, beans, nuts, bananas, and spinach. Zinc deficiency is recognized as a global health problem, impacting developing countries to a great extent. Zinc deficiency can affect infancy, growth and stunting, and cognitive development in children.

Zinc's role in brain functioning

Zinc is present in synaptic vesicles in a group of glutamatergic neurons in the brain that may modulate responses at receptors for a lot of different neurotransmitters. This includes both excitatory and inhibitory, the N-methyl-D-aspartate (NMDA) and γ-Aminobutyric acid ($GABA_A$) receptors playing a part in depression and anxiety (DiGirolamo & Ramirez-Zea, 2009). Due to the significance of zinc metabolism in the brain, it has been associated with neurological dysfunction and brain pathology (Cuajungco & Lees, 1997). Animal studies have shown that chronic zinc deficiency can cause central nervous system abnormalities such as affecting neuronal function in the hippocampal mossy fibers (Cuajungco & Lees, 1997). Low zinc status also shows that cell growth is delayed where MT-I protein is rapidly degraded when zinc is limited (Palmiter, 1995). Metallothioneins (MTs) are cysteine-rich metal-binding proteins that are important for zinc homeostasis.

Across different studies, multiple researchers have tried to determine the mechanisms in which zinc may play a role in mental health dysfunctions including depression and ADHD. One possible pathway for depression is through zinc's effects on neurotransmitters at NMDA receptors where NMDA glutamate receptors in depressed patients may be supersensitive and with dysregulation of glutamate (DiGirolamo & Ramirez-Zea, 2009). Zinc is a strong inhibitor of the NMDA receptor and recent studies on animals have shown that zinc can create an antidepressant-like effect in animals along with amplifying the effect of antidepressant medications like for example, imipramine (Cieślik et al., 2007). Other researchers have thought that zinc could exhibit antidepressant effects through direct or indirect activation of A_1 and A_{2A} receptors, or an increase in the number of neuroprotective factors such as glutathione (Franco et al., 2008).

Mechanisms have also been suggested for the relation between zinc and ADHD symptoms, specifically through modifications in the neurotransmitters dopamine and serotonin (Bilici et al., 2004). Zinc is essential for producing and modulating melatonin which serves to regulate the function of dopamine and for the conversion of dietary pyridoxine to pyridoxal phosphate, which is then necessary for the conversion of tryptophan to serotonin. As seen through several proposed mechanisms, dopamine and serotonin neurotransmitters may be involved in ADHD. With zinc supplementation, ADHD symptoms such as impulsivity maybe are improved because zinc may solve the reduction of melatonin and serotonin synthesis (Franco et al., 2008). N2 is an event-related potential component and an artifact of the EGG. The N2 wave in the frontal and parietal regions of the brain shows and measures focused attention to stimulus features (Yorbik et al., 2008). The N2 component reflects focused attention to stimulating features and zinc levels appear to have an influence on information processing. Lower zinc levels seem to affect the N2 wave, suggesting to be in relation with inhibitory processing. Results from this study suggest that differences in N2 latencies in frontal and parietal regions could reflect the information processing in ADHD caused by the effects of zinc deficiency (Yorbik et al., 2008). Since dopamine and serotonin neurotransmitters may be involved in both ADHD and depression, there may be a pathway linking zinc to both disorders. However, more research needs to be done to understand the mechanisms involved and any familiar pathways between ADHD and depression.

Zinc deficiency and brain development

Zinc plays a vital role in the brain where it binds to proteins that contribute to the structure and function of the brain. Zinc is most present in the limbic system consisting of the hippocampus, amygdala, and glutaminergic neurons containing zinc (Takeda, 2000). Low dietary intake of zinc may influence zinc homeostasis in the brain leading to alterations in behavior and mental functioning (Takeda, 2000). In cases of severe zinc deficiency effects such as abnormal cerebellar function can arise and can impair behavioral and emotional responses (Black, 1998). A study looking into dietary zinc intake and serum levels in young female students found that serum zinc levels and dietary intake were lower in depressed girls compared to girls not experiencing depression (Amani et al., 2010). Changes in behavior such as reduced activity and responsiveness also seem to be a consequence of inadequate dietary intake of zinc as shown in animals that were put through a period of zinc deprivation. The behavior of these animals was then tested and showed lethargy and impaired learning and memorization among the animals (Golub et al., 1995). Although this piece of data is relevant only to animals, it suggests a possible consequence of zinc deficiency that can occur in humans and the need for clinical focused research.

Through extensive research, it has been suggested that nutritional deficiency occurs in the conditions of poverty and poor caregiving habits (Black, 1998). The causes of developmental problems common in undernourished children often form from a combination of nutritional and environmental factors. Deficient or delayed cognitive development and motor development are often seen in undernourished children. Although studies suggest that zinc plays an important role in children's activity, attention, and development, there are no clear mechanistic explanations for the relationship between the development of these areas and zinc (Black, 1998). Evidence on the impacts of zinc deficiency has shown to be the most prominent during the stage of infancy. Motor skills in preterm infants particularly tend to be delayed and it is found that a nutritional diet with an increased zinc intake influences the development of motor skills in very-low-birth-weight infants (Friel et al., 1993). Another study taking a look at activity patterns in infants in Guatemala found that 7 months of zinc supplementation had a significant effect on infant activity and children receiving zinc spent 3.4% more time in "high-movement" activities (Bentley et al., 1997). Low levels of zinc during the neonatal period were associated with less attention and poor motor functioning in infants, however, the supplementation of zinc has been linked with improved motor development in infants with very low birth weight. Additionally, more functional activity was found in Guatemalan infants and children receiving zinc supplementation.

Interpreting the mentioned studies suggests zinc deficiency may have an influence on changes in neuropsychological functions such as activity and attention. Another possible impact of zinc deficiency that emerged from looking into the data of the conducted studies showed that activity levels were reduced which could inhibit the growth of cognitive development. During the early stages of child development, a child's brain is exposed to different stimulating experiences that help form the in becoming a functioning member of society. One of the ways in which young children learn the necessary skills they need to navigate different situations and environments is through playtime. The act of participating in play is useful for processing new information both cognitively and emotionally as a child forms new neural connections. Neurons do not start off in a mature state and instead take time to develop through practicing new behaviors and experimenting with solutions (Nijhof et al., 2018). Zinc contributes to the necessary nutritional intake a young developing body needs in order to participate in activities that require a fair share of energy and concentration. Another common theme shared in the mentioned conducted studies was that age of the child is another factor to take into consideration as the impacts of zinc deficiency may be stronger in different stages of child development due to experienced rapid periods of growth. However, more studies need to be conducted to reach this conclusion, especially in marginalized populations.

Tying all these findings together forms a path model proposing neuropsychological functioning and motor development moderate the relationship between zinc deficiency and cognitive development (Black, 1998). Two other important determinants to a child's development based on the model pathway where age, neuropsychological attention, activity, and motor development all contribute to the development of a child's cognitive abilities include the caregiving environment and socioeconomic status.

Zinc absorption

The site of absorption for zinc is thought to be in the proximal small bowel, either in the distal duodenum or proximal jejunum (Krebs, 2000). Absorption of zinc can be influenced by the amount of zinc present in the intestinal lumen, the availability of dietary sources that contain zinc such as human milk or animal proteins, and inhibitors (Krebs, 2000). Protein, depending on the amount and type, affects zinc absorption. Even the smallest amounts of animal protein can increase the efficiency of absorption and amount of zinc (Krebs, 2000). Inositol hexaphosphates and pentaphosphates (phytic acid) bind to zinc forming poorly soluble complexes that reduce the absorption of zinc. The high phytate to zinc molar ratio in plant-based diets has been thought to be a contributing factor to zinc deficiency (Gibson, 1994) Phytate works as an inhibitor of zinc, negatively affecting its zinc absorption. Plant products with grain and legumes usually contain high levels of phytate.

Zinc dietary requirement for development

The needed intake starts with 3 mg/day for growing children and increases to 8 mg/day in adult females and 11mg/day in males (Zinc, 2019). The daily recommended intake of zinc for children is as follows: 3 mg/day for children less than 4 years of age, 5mg/day for children between the ages of 4 and 8 years of age, and 8 mg/day for children between the ages of 9 and 13 years of age. For women that are not pregnant and non-lactating, the daily recommended intake of zinc is 9 mg/day. The daily recommended intake of zinc for men is 11 mg/day. Finally, the daily recommended intake of zinc for pregnant and breastfeeding women is between 11 and 12 mg/day (Zinc, 2019). Based on these recommendations, it is apparent that children require an increase in zinc intake as they progress through the different stages of development. When compared to adults, these recommendations also increase, but pregnant and lactating women suggest the need for more of this mineral since the woman's body needs to share the absorption with her unborn child. Building on the concept that higher zinc demand is required in children's development, deficiency is more likely to be prevalent among this population.

Zinc deficiency: environment and socioeconomic factors

In developing countries like Latin America, zinc deficiency is a factor of malnutrition. A study conducted in Colombia aiming to implement government aid programs in an effort to provide the children from impoverished communities with zinc supplementation found that there is a correlation between wealth, food security, and enrollment in nutritional support programs. In Colombia and according to what has been reported in other developing countries, children under 5 years of age suffered from zinc deficiency (Pinzón-Rondón et al., 2019). Children developing in a disadvantaged setting are more likely to suffer from zinc deficiency. This is likely due to the inequality in access to food, health services, and education. As explored in Colombia, a study conducted in 2019 aimed to assess the role nutritional support programs had on zinc deficiency in Colombian children. A national survey specific to Colombia measures variables such as socioeconomic status, food security, maternal education level, urban vs rural, and whether they were enrolled in a nutritional support program. This study found that wealth and enrollment in nutritional support programs are associated with zinc deficiency. The study found an existing large gap between the children that were able to access the nutritional program (22%) and children who were food insecure (71%) (Pinzón-Rondón et al., 2019). Based on these results it can be noted that only a small portion of the people living in poor to extreme poverty situations was accounted for in the implemented nutritional support programs. Reinforcing nutritional programs and overall support in areas reporting high poverty and food insecurity can prove to be an effective approach to alleviating zinc deficiency influenced by food insecurity in Colombia. Although these findings are specific to Colombia and every country has its own unique factors contributing to food insecurity, the implementation of nutritional support programs can prove to be effective in supporting populations at risk of zinc deficiency. Similar results were found in Mexican rural children of ages 12-29 months that showed a positive impact on zinc levels through the implementation program, *Oportunidades* (Ramírez-Silva et al., 2013). Families of low-income Mexican children are provided with cash transfers, nutritional education, health services, and food supplements in an effort to have a positive impact on the dietary inequality existing in this population of children. Another study that implemented a fortified nutritional approach also had positive effects in improving zinc status among children in Thailand. Low phytate in polished rice made it ideal to produce triple-fortified rice grains with zinc and proved to be useful in improving zinc status in school children as rice is a widely consumed grain throughout developing countries (Pinkaew et al., 2013).

Another factor involved in the malnutrition developing countries suffer comes from their plant-based diet. This limits the intake of zinc and its availability in the body because of the lack of animal-protein intake (Abuya et al., 2012). Animal meats provide higher sources of zinc absorption compared to plant-based diets that this population heavily relies on as a source of nutrition. As discussed before, plant-based diets provide inhibitor factors that affect the absorption of zinc in the body.

Epidemiology of zinc deficiency

Zinc's vital role in multiple cellular processes and mechanisms allow it to link with other health concerns such as anemia. A study looking into the association of zinc deficiency with anemia in young children in rural Guatemala showed that the odds were three times more likely for a child to develop anemia if they were zinc deficient (Palacios et al., 2020). Zinc deficiency associated with anemia is prevalent in infants and toddlers because of their vulnerable position to micronutrient deficiencies while their growth rapidly increases (Palacios et al., 2020). In the first months of an infant's life, breast milk is able to sustain the zinc and iron levels the growing infant needs, but after 4-6 months the levels of these minerals are exhausted (Palacios et al., 2020). Once the infant reaches the 7-month age range, breast milk only provides 0.5mg/day of zinc, making up only 20% of the needed requirement for a growing infant above 7-months of age (Palacios et al., 2020). Infants and toddlers in rural Guatemala lack access to animal source foods and proteins that contain a sufficient amount of zinc and iron that the body can take in (Palacios et al., 2020). Cultural practices and plant-based diets may also contribute to the lack of nutrition deficiencies in infants and toddlers that deprive them of the proper nutrients (Palacios et al., 2020). Participants in the study were of Kaqchikel Mayan origin who continue to implement a lot of their practices such as incorporating maize into their daily meal despite its negative effect on zinc absorption. Maize is a staple item among Latin Americans that holds a lot of traditional value and is incorporated into almost every meal. Plant-based diets stem from a combination of ingrained cultural practices, but also as a result of food insecurity.

Limited information is available on the severity of zinc deficiency impacting the development of children in Latin America and the Caribbean. The only countries with available data to report were Mexico, Colombia, Ecuador, and Guatemala on zinc deficiency impacting women and children in these populations. Taking the biochemical evidence provided from the four available countries suggests that the neighboring Latin and Caribbean countries also show a risk of a high prevalence of zinc deficiency in children. Reporting an estimated inadequate zinc intake of more than 25%, these countries were Belize, Bolivia, El Salvador, Guatemala, Haiti, Honduras, Nicaragua, and Saint Vincent and the Grenadines (Cediel et al., 2015). These countries require prioritization for biochemical and nutritional assessment to find the zinc intake of each country and administer proper nutritional support services catered to each country. It is difficult to know just how much the population of each country is suffering from zinc deficiency because of the lack of clinical assessment and awareness. However, based on the available data, zinc deficiency is a prevalent health problem that other Latin American and Caribbean countries could be suffering from at more alarming levels but is not known due to the lack of information and representation available.

The needed intake, or nutritional adequacy, of zinc, depends on both the amount and bioavailability in the diet. Meat from animal sources has a high source of zinc and is a good source of other essential micronutrients like iron, vitamin B-12, and selenium. These micronutrients have an important function in metabolic and physiological processes. Zinc, in particular, is readily available once ingested due to L-amino acids and cysteine-containing peptides that are released and form soluble ligands with zinc (Gibson, 1994). In many developing countries, including Latin America, the availability of animal protein is low and therefore contributes to a relatively low intake of zinc. Alternatively, a lot of their food source comes from a plant-based diet. In a rural setting, this diet can consist of cereals and starchy root vegetables that tend to be the main source of zinc in their diets. As previously mentioned, plant diets contain high amounts of phytic acid, responsible for storing phosphorus in cereals, legumes, and oleaginous seeds, and are a major inhibitor of zinc absorption. Another factor contributing to the inadequate absorption of zinc in the body in individuals from developing countries is the loss of zinc through excessive sweating due to hot and humid climates. The climate of Latin America ranges from hot and humid to desert-like conditions. Exposure to extreme temperatures in itself can stimulate responses in the body leading to changes in zinc metabolism and the range of sweat losses of zinc is from 0.5 to 1 mg per liter (Institute of Medicine (US) Committee on Military Nutrition Research & Marriot, 1993). The people living in Latin America are usually required to do extra physical activity such as walking throughout the day because of the culture and lifestyle of rural living revolving around agricultural work.

Zinc deficiency is a major cause of malnutrition in many countries worldwide. Malnutrition has been linked to poverty across the world since research has found that high levels of malnutrition are found in areas of extreme poverty. There has been evidence suggesting that health outcomes like malnutrition are influenced by social determinants such as an individual's lifestyle and work. Many Latin Americans face poverty in their everyday life making it significantly challenging to access sufficient, nutritious food. Poverty yields a financial limitation in terms of the food that can be purchased, resulting in the consumption of cheap food high in fat and carbohydrates as opposed to nutritiously filling food (Siddiqui et al., 2020). Even though the consumption of carbohydrates and fats spikes energy levels, these food types reduce the intake of quality nutrition and nutrients (Siddiqui et al., 2020). Poverty and malnutrition are interlinked and give rise to nutritional deficiencies such as zinc deficiency due to the constraints faced in accessing quality nutrition.

The impact of weather and climate change

As mentioned above, weather can contribute to zinc absorption in the body as heat causes the body to sweat the mineral out, however, excessive heat and changes in temperature can also affect zinc availability in crops. A major component of Latin America's economy depends on agriculture, and the current climate change is impacting Latin America's food security. With a big population living in poverty where for example extreme poverty is defined as those living less than the U.S. $1.90 per day, relying heavily on the food they produce, seasonal labor work, and food from natural sources (Iannotti et al., 2012). Consequently, climate change has an impact on farmers, their families, and the rest of the population because of the threat it poses to food security. Recent research led by Sam Myers, Director of the Planetary Health Alliance at the Harvard Chan School, found that increasing concentrations of carbon dioxide lower the nutrients like zinc in food crops. According to Myers, when crops like wheat, corn, rice, and soy are exposed to the atmospheric carbon dioxide levels predicted for 2050, the plants lost as much as 10% of their zinc, 5% of their iron, and 8% of their protein (Myers et al., 2015). This is alarming when considering a lot of people from Latin America and other developing countries depend on plant-based diets for their daily intake of food and nutrients. This also brings up a social justice concern when many studies have shown wealthier nations are the main contributors to CO2 emissions meanwhile poorer nations are the most vulnerable to these impacts since they receive the lowest portion of their zinc intake from animal sources. They are put at more risk of zinc deficiency leading to problems that are responsible for brain development in children since the majority of their nutrients come from plants.

Zinc deficiency: an undue burden placed on mothers

Mother figures play an important role in protecting the health of a developing child. Especially in the Latin American culture where the role of the caretaker is given to the woman and the provider is given to the man. Partly because of this gender role, it is assumed mothers tend to have the children's best interest and play a bigger role in raising children. The perception that women take on greater responsibility for a child's wellbeing is not only based on an assumption but is also supported through observations from studies conducted worldwide (Ekbrand & Halleröd, 2018). For example, a study looking into the conditional cash transfer programs in low-income countries such as the Brazilian Program Bolsa Família and the Mexican program Oportunidades, typically give the money transfers to the mothers over the father because of their initiative to assume responsibility for the children (Ekbrand & Halleröd, 2018). These mothers were responsible for meeting the program's requirements for the cash transfers including committing to school attendance and nutrition for the children. Based on the role mothers play in the well-being of a child it is also assumed that the educational level of mothers greatly impacts the nutritional status of a child. Research has shown there is a link between a mother's educational level and her child's nutrition. Many studies including studies focused on Jamaica, Bolivia, and Kenya have shown there is an association between mothers' educational level and nutritional outcomes in children. Children born to educated women were impacted less by malnutrition exhibited through underweight and stunting in children (Abuya et al., 2012). Due to the poverty and economic instability many Latin American countries face, women's education is not prioritized. This again ties back to the consequences of poverty that limit who has access to education. When parents are faced with limitations in providing an education for their children, they often chose to send boys to school with the reasoning being that will become future "breadwinners" (Roberts, 2012). Due to these socio-economic and family structure factors, women are subjected to one approach in dealing with the health, well-being, and nutrition of their children moving them away from the notion that certain food holds nutritious elements and can be useful in preventing illnesses in cognitive and mental health development.

Zinc deficiency: Focus on El Salvador and Guatemala

Like most Central American countries, El Salvador faced a brutal 12-year-long civil war, and although the country has come a long way in recovery, it continues to be impacted by the violence and economic instability brought upon the country by the war. The current changes to climate have also had negative consequences on crop cultivation and the nutritional value of the plants. All these factors contribute to the ongoing cycle of poverty found in this small but densely populated country. The 2012 National Household Survey found that 34.5% of the population lives in extreme poverty ranging from 47.2% to 60% in the most vulnerable municipalities, where chronic child malnutrition prevails. El Salvador's economy depends on importations and remittances making the poor even more vulnerable to the environmental changes and external changes since they rely heavily on outside sources for food. Food insecurity and malnutrition in El Salvador are associated with social inequality, unemployment, low salaries, and inaccessibility to education which affects nutritional education and food production (SANNHOS, 2019). In El Salvador there are no existing studies on zinc deficiency that show a deficiency in the population however based on an analysis of the alimentation status conducted by the Institute Of Nutrition of Central America and Panamá (INCAP) in 2011, it was concluded that the average amount of zinc available in the food consumed does not even cover half of the recommended intake per capita (SANNHOS, 2019). Considering El Salvador is one of the countries with a high present population of delayed development in the growth of children, the Grupo Consultivo Internacional de Zinc (IZINCG) suggested the important role zinc plays in the high percentage found in this population.

As mentioned before, the primary factors contributing to zinc deficiency in low-income countries like El Salvador are the insufficient intake of zinc because of the food consumed which also contains relatively low levels of zinc. The intake of food with a high content of zinc inhibitors also affects the absorption of zinc in the body of a growing child. Populations at risk consume limited quantities of food that is high in zinc absorption such as red meats and other animal products because of its cost. This is the case with El Salvador's population that habitually consumes a grain-based diet and legumes, which contains significant amounts of phytates and are responsible for strong zinc inhibitors. Other factors to consider, since a proper case study has yet to be conducted for the prevalence of zinc deficiency in Salvadoran children, are the inadequate practice of breastfeeding and the rapid growth spurts that occur during childhood requiring an increase in nutritional requirements that is not easily accessible and effects it brings on health. Among all the health consequences brought by the deficiency of this mineral, an increase in the appearance of infectious diseases such as diarrhea and alterations in cognitive capacity was observed in the development of children (Lineamientos técnicos para la suplementación con micronutrientes en el ciclo de vida, n.d). When a child experiences an episode of diarrhea, large amounts of zinc are lost leaving the child's body vulnerable as it recovers. The limited amount of zinc available in food sources restricts the amount of zinc that can be absorbed by the body and delays the child's body from recovering and keeping them healthy as they continue their journey of growth and development. Nutritional programs helping to replace and keep a steady intake of zinc need to implement in developing countries such as El Salvador and will be discussed in a later section of this paper.

Guatemala, a neighboring country to El Salvador, also experienced drastic effects on its economy and society influenced by a 36-year-long civil war. However, unlike in El Salvador, there is data available on the effects zinc deficiency has on the cognitive development and mental of children. Guatemala is one of the few Central American countries with national biochemical data available indicating children under 6 years of age and women between the ages of 12 and 49 years of age had a high prevalence of zinc deficiency. Children from rural areas in Guatemala were found to have a higher prevalence of zinc deficiency (41.8%) than children from urban areas (24.8%) (Palacios et al., 2020). A higher prevalence of zinc deficiency was also found in indigenous children (41.2%) compared to non-indigenous children (29.8%) (Cediel et al., 2015). A study looking into the relationship between anemia and zinc deficiency in infants, toddlers, and preschoolers found that more than 50% of the family households participating in the study reported food insecurity and more than half of the infants and toddlers had anemia while also experiencing high rates of zinc deficiency anemia (Palacios et al., 2020). Infants, toddlers, and preschoolers not experiencing anemia also had a prevalence of zinc deficiency of 36.5% (Palacios et al., 2020). These findings are consistent with data showing vulnerable populations are subject to a variety of micronutrient deficiencies coexisting such as zinc is associated with anemia in children ranging from 0 to 24 months of age.

Societal factors and feeding practices could impact the ability of Guatemalan families in accessing quality nutritional food. Iannotti and colleagues looked into how economic conditions affect micronutrient nutrition specifically focusing on food prices and poverty in Guatemala found that zinc showed the greatest increase in inadequate intake as income was reduced. Another factor contributing to the lack of nutritional intake is the standard diet that is mostly plant-based. Similar to that of the Salvadoran population, a lot of the crops are high in phytate working as inhibitors for mineral absorption such as zinc. Traditional maize has been labeled as the main grain of the Mayan people for over a thousand years and continues to be a commonly used grain in the country (Palacios et al., 2020). Families are limited to plant-based diets influenced by cultural practices and low economic conditions leaving them exposed to nutritional deficiencies such as the vital zinc mineral.

Impacts of zinc supplementation

Population-based studies looking into the effect of zinc intake on children and infants' emotional and behavioral responses have provided mixed results where zinc has had positive effects on children's psychological development and behavior, while others show no support. For example, in one study 6-9-month-old infants in Guatemala were given a daily intake of 10 mg of zinc as zinc sulfate over 7 months. After the 7-month period, infants treated with zinc were more likely to be seen sitting and involved in playing activities compared to the infants not treated with zinc that were observed in low-energy actions like laying down (Bentley et al., 1997). Infants treated with zinc were less likely to be observed crying. The findings from this study were consistent with other studies that showed a steady increase in activity levels due to the influence of zinc supplementation.

Research conducted in northeast Brazil where a majority of the population is poor and the economy is heavily dependent on sugar-cane production found that zinc supplementation could have an effect in reversing poor responsiveness displayed by low birth weight infants. Infants receiving 5 mg zinc supplementation were found to be more responsive and friendly towards the tester and showed less fearful and reserved behavior compared to the other infants in the study (Ashworth et al., 1998). Malnourished infants/children usually display shy and inhibited behavior, so it is possible that zinc deficiency feeds into this behavioral characteristic. Another looking into the impact of zinc supplementation on the mental health of school-age children in Guatemala revealed no significant differences in mental health outcomes between zinc and the control groups. On the other hand, this study did provide evidence of decreasing symptoms of depression and anxiety by increasing serum zinc concentrations in children that were at risk of zinc deficiency (DiGirolamo et al., 2010). Looking at the data from these mentioned studies suggests there is supporting evidence for zinc supplementation in increases of alertness, activity levels, and engagement in exploratory behavior that support the development of motor and cognitive function in infants and children. Since there continues to be a gap in the available data on the impact of zinc deficiency in developing countries, and the identification of the possible pathways between zinc and mental health disorders, further research needs to be implemented to explore the potentially positive role of zinc for treating mental health disorders that continue to be a significant public issue. Especially since zinc supplementation for infants in developing countries has been linked to have positive effects on emotional tone, responsiveness, and activity levels.

Concluding Remarks:

Zinc deficiency is a prevalent problem among the population of children in Latin American countries. Poverty and food insecurity are common contributors to micronutrient deficiencies such as zinc deficiency impacting neuropsychological functions such as activity and attention in young children. Financial constraints affect access to quality nutrition limiting families living in poor rural areas to plant-based diets. Providing nutrition education and food supplements also proves to be a challenge as many of these populations aren't accounted for. The majority of Latin American countries do not have biochemical data available to analyze the prevalence of zinc deficiency in children and the impacts it has on their cognitive function and mental health. Only Mexico, Colombia, Ecuador, and Guatemala had available data on the high prevalence of zinc deficiency affecting the population of children and women.

Zinc supplementation through nutritional support programs and government aid programs has demonstrated a positive effect on zinc levels through slight improvements in behavior such as increased alertness and activity levels. This means that many children would benefit from intervention programs that make accessing proper nutrition and providing the necessary nutrients for brain and body development easier and at no cost to the families. This also aligns with the concept that sometimes the best approach for combating health illnesses is through prevention and preventative programs. Empowering women is a good place to start due to the important role they place in safeguarding the well-being of their children. Empowering women through education has shown to help them assume important political roles which often are focused on improving health deprivation in children and women (Wängnerud & Sundell, 2012). Children who are born to educated mothers are less likely to suffer malnutrition because they have a better understanding of healthcare and are able to provide safer environments for their children. Maternal education can impact how diseases and causes are viewed as well as influence mothers to adopt preventative practices that can be beneficial for child nutrition.

Limited data on the prevalence of zinc deficiency makes it difficult to assess and implement therapeutic strategies in Latin American countries. This is concerning considering the important role zinc plays in the overwell being of a developing child. Although more research is needed in understanding the mechanistic pathways zinc participates in, studies have shown the influences zinc has on neurophysical dysfunction leading to other health problems. Children of marginalized communities in Central and Latin America need more representation in research in order to combat zinc deficiency which is recognized as a global health problem.

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