Micro and Macronutrients in Children: Benefits, Evidence and Dosing

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Abstract

No other stage in one's life is more critical than during infancy and childhood for ensuring that children get appropriate and balanced nutrition. Nutrients in adequate amounts and with the proper composition are critical for growth, functional outcomes such as cognition and immune response, as well as the metabolic programming of long-term health and well-being throughout this dynamic time. According to guidelines from the World Health Organization and the United Nations Children's Fund, the energy and nutrients necessary for babies' growth and development are not met solely by breast milk beyond the age of six months, and extra meals are required to satisfy those requirements. Human development, especially in infants and children, needs a sufficient supply of nutrients. As a result, a balanced diet is essential for healthy growth in order to ensure optimal macronutrient and micronutrient intake. Macronutrients are the chemicals that individuals consume in the largest number and are separated into three categories: carbohydrates, proteins, and fats. Carbohydrates are the most abundant macronutrient, followed by proteins and fats. Micronutrients such as zinc, iron, vitamin D, and folic acid, which are provided in small quantities but are critical for good development in the pediatric period, are introduced in adequate amounts. Several major macro- and micronutrients for children's growth and development are discussed in this review, with a particular emphasis on low- and middle-income countries like India. Antioxidants and other miscellaneous nutrients are also discussed.

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Background

Undernutrition, characterized by stunted development and micronutrient deficiencies, is a significant cause of death and disability-adjusted life-years loss in children under five years (1, 2). A lack of nutrients during adolescence period of rapid growth might result in delayed and stunted linear growth and poor organ remodeling (3). While undernutrition, including stunting and wasting, is decreasing in children under 5 years, rising rates of overweight and obese children and adolescents are causes for concern (3). Thus, many low- and middle-income countries now have a twin burden of malnutrition, with increasing rates of overweight and obese children on one hand and chronic undernutrition on the other (3).

An estimated 45% of child mortality is linked to malnutrition. Globally, in 2020, it was assessed that 149 million children below the age of five were stunted (too short for their age), 45 million were wasted (too thin for their height), and 38.9 million were overweight or obese (4).

Child nutrition from diet; is it adequate?

Outlook of child nutrition in India

Despite all the progress in health and development, over 70% of children in India remain malnourished, and 40% are stunted. (5). The national Family Health Survey 2015–16 showed 23% of children aged 6–23 months had a diverse diet (5). The survey found that most children eat more grains and fewer fruits, vegetables, nuts, legumes, eggs, and meat. In the poorest households, just 18% of children received a diversified diet, compared to 28% in the wealthiest households (5). The study found that only 17% of children of uneducated mothers ate a diverse diet, compared to 30% of children of educated mothers (5). The most notable difference between children of different wealth groups was dairy consumption (5). According to another analysis, Indian diets, across different states and income groups, are unhealthy with more consumption of cereals and insufficient intake of proteins, fruits, and vegetables.

Dietary nutritional recommendations

Estimated Average Requirements (EAR) in Indians and Recommended Dietary Allowance in Children 1–18 yrs is presented in Table 1(6, 7). Acceptable Macronutrient Distribution Ranges (AMDR) as Percent of Energy (%E) is presented in Table 2 (8, 9). The research shows that the Indian diet does not provide the needed macro- and micronutrients for healthy child growth and development. Furthermore, we discuss the need to reassess nutrients and nutritional supplements, due to undervalued diets in terms of proteins, amino acids (AA), omega 3 fatty acids, vitamins, and antioxidants, in order to assess their potential role in preventing various communicable and noncommunicable diseases among children. This review also discusses the advantages, evidence, and doses of different critical macro and micronutrients to help parents decide when, how, and why to supplement a child's diet.

Macronutrients, dietary source, contribution in child development, and effects of deficiency

Proteins and Amino Acids (AAs)

Overview of protein and amino acids

A deficiency of dietary proteins results in low birth weight, stunting, wasting, and underweight. Sufficient dietary proteins during pregnancy and early childhood are critical for normal growth. Extreme deficiency of proteins can lead to metabolic abnormalities and delayed development and lifelong implications (10-12).

Dietary source of protein and gaps in Indian Diet

Animal-sourced foods (ASFs) are abundant in calories, high-quality protein, and other essential micronutrients; early childhood exposure to a completely vegetarian diet—or in utero through maternal nutrition—could be a substantial risk factor for malnutrition in India (13, 14). India has the highest rates of child stunting (38.4%), wasting (18.7%), and anaemia (58.4%) among preschool children in the world, and India is by far the most significant contributor to the global burden of these diseases (14). According to the latest Indian Comprehensive National Nutrition Survey (CNNS; 112,000 children), 55% of children and adolescents consumed (lacto-) vegetarian diets, while 40% ate non-vegetarian diets; the rest consumed ovo-lacto-vegetarian diets (13). Although Indian children's crude protein intake appears acceptable compared to their needs, proteins should also be assessed by their quality, which involves measuring the limiting essential amino acid (IAA) concentration of the proteins consumed and their digestibility (13). Legumes are consumed in insufficient quantities in habitual Indian diets to be useful as complementing foods, with an average intake of 30 g/capita/d and mean IAA digestibility ranging from 63–75% (13). Recent national data analysis has revealed that in India, growth faltering begins in the first year of life and stabilizes around the age of two years. After exclusive breastfeeding, the child's diet should include high-quality complimentary meals that are easily digestible (13). Diet rich in ASF shows that adding 200 or 50 grams of milk or egg to a child's daily diet improves the digestibility of amino acids by 100% and lowers the risk of protein insufficiency from 29 to 10% (13).

Fats

Overview of fats

During prenatal and postnatal life, long-chain polyunsaturated fatty acids (LCPUFA), such as arachidonic acid (n-6 PUFA) and docosahexaenoic acid (n-3 PUFA), rapidly accumulate in the brain. These are critical for the central nervous system's and retina's growth and function. Polyunsaturated fatty acids (PUFA) that are physiologically important include omega-3 (alpha-linolenic acid [ALA], docosahexaenoic acid [DHA], and eicosapentaenoic acid [EPA]) and omega-6 (linoleic acid, arachidonic acid [AA]) (15). DHA is connected with optic nerve and brain tissue and improves its function by rejuvenating brain cells; EPA stimulates blood circulation and lowers blood cholesterol; Omega-6 fatty acids, in general, cause inflammation and thrombus development, whereas omega-3 fatty acids have anti-inflammatory, anti-arrhythmic, and anti-thrombotic properties (15).

Dietary source of fats and effect on child development

WHO advises a 5-10:1 ratio of omega-3 to omega-6 absorbed by diet or supplement? Most Indians take omega-6 and omega-3 fatty acids in a 30-70:1 ratio (16). Fish and other seafoods are high in omega-3 fatty acids; besides these, fortified foods (yogurt, soy beverages, infant formulae, and vitamin powders) are excellent options. Corn oil, grapeseed oil, soybean oil, and sunflower oil are high in omega-6 fatty acids. According to Food and Agriculture Organization of the United Nations (FAO)/WHO, the recommended dietary intake (RDA) for total PUFA in children aged 6 to 24 months is 15 %E and 11%E in children aged 2 to 18 years (22–24) (15). LCPUFA is essential for visual development during childhood. Compared to infants fed formulas lacking LCPUFA, breastfed newborns show enhanced electroretinographic function at six weeks and more mature visual acuity by four months. The human brain is 60% fat, with omega-3 fatty acid—DHA—abundant in neuronal membranes to sustain neurological function. DHA is heavily collected in brain areas related to memory and learning, contributing to a high level of cognitive function. DHA profoundly affects photoreceptor membranes and neurotransmitters involved in signal transduction, rod and cone cell development, rhodopsin activation, and neural dendritic connectivity. DHA supplementation can play a vital role in the signal activation in the retina (17, 18). The literature reports the anti-inflammatory role of DHA in the retina, which could be attributed to significant changes in the fatty acid composition of retinal phospholipids after omega-3 intake, leading to a significant increase in the EPA/AA ratio. Increased levels of DHA in phospholipids promote anti-inflammatory action by inhibiting the formation of cyclooxy-genase and lipoxygenase products of AA and stimulate the formation of less potent series eicosanoids (17, 18).

Micronutrients, dietary source, contribution in child development, and effects of deficiency

Overview of micronutrients

India is home to over half of the world's micronutrient-deficient population. According to the results of India's latest National Health Survey, 58.5% of children are anaemic at the national level, and the FAO estimates that 74% are at risk of anaemia due to iron deficiency, and 62 and 31% are at risk of vitamin A and iodine deficiency, respectively (19). Deficits in these areas throughout childhood have a variety of serious consequences, including higher mortality, morbidity, and physical and mental abnormalities. Evidence suggests that iron, zinc, and vitamin B6 shortages are prevalent, with 41%, 25%, and 6% of the population, respectively, falling below the EAR (19). Although iron and B-vitamin deficiency may not always lead to anaemia, they can be a significant precursor (19). According to the NFHS-4 2015-16 survey's biomarker estimates of haemoglobin concentra-tions, 50%, 53%, and 59% of pregnant women, women of reproductive age, and children under the age of five were anaemic, respectively (19). Anaemia (24–41%), iron insufficiency (17–32%), vitamin B12 deficiency (14–31%), and folate deficiency (23–37%) were all common among children and adolescents in India, according to the Comprehensive National Nutrition Survey. Calcium, vitamin A, B12, and folate insufficiency, on the other hand, are at prevalent risk of deficiency, with 94%, 89%, and 81% of the population at risk, respectively (19). Dietary inconsistencies, particularly in fruits, vegetables, pulses, and animal products, are thought to be accountable for widespread micronutrient deficiencies. Vitamins and minerals in perishable foods like fruits, vegetables, and animal products have higher supply chain losses than macronutrients (19). Vitamins are essential micronutrients that are synthesized by plants and microorganisms. Based on their solubility, they can be categorized into two groups exhibiting significantly different biological characteristics. Classification of vitamins, minerals and other miscellaneous substances, dietary sources, biological roles, and deficiency conditions are presented in **Table 3**.

Nutritional supplements to fulfil the nutrition gaps Available evidence for nutritional supplementation benefits in different subsets of children

Braun et al. reported that a 10 gm increase in total protein intake/day at 1 year of age was significantly associated with greater height, higher weight, and higher BMI up to the age of 9 years (11).

In the first year of life, a constant supply of DHA in both human milk and baby food increased visual development in infants, according to an experiment conducted by Hoffman et al (20). Similarly, Birch et al. found that supplementing infant formula milk with 0.72% arachidonic acid (AA) and 0.36% DHA during the first four months of life was associated with a mean seven-point rise in the mental developmental index (MDI) at 18 months. Compared to the control group, both the motor and cognitive subscales of the MDI exhibited a significant developmental advantage in the DHA- and DHA+AA-supplemented groups (21).

A comprehensive analysis of 29 randomized controlled trials (RCT) examined the role of omega 3/6 fatty acids in children and early adolescents found that omega 3/6 might improve learning, reading, attention, spelling, and reduce aggressiveness and hyperactivity in ADHD and low omega 3 populations. DHA supplementation may alter children's brain function and cognitive capacity. A community-based cohort research linked increased LCPUFA (EPA, DHA, DPA) diet to larger retinal arterioles in 17-year-old females (54).(22).

A meta-analysis by Mayo et al. comprising 43 trials and 215,633 children determined the effect of vitamin A supplementation in children under five years of age, and reported 24% reduction in all-cause mortality and 28% reduction in overall mortality associated with diarrhoea (23). Overall, diarrhoea incidence decreased 15%, measles incidence decreased 50%, and reduced prevalence of visual disorders such as night blindness and xerophthalmia was noted. Vomiting was recorded in the first 48 hours of supplementation (23). In a meta-analysis, Hemilia and Louhiala analysed the effects of vitamin C in the prevention and treatment of pneumonia (24). They reported three studies showing >80% lower incidence of pneumonia in the groups who were taking vitamin C, thus supporting its potential role in reducing the risk of pneumonia particularly in individuals with deficient levels of vitamin C (24). Constantini et al. conducted an RCT in adolescent swimmers (12–17 y) to determine the effect of vitamin C supplementation on the length and severity of upper respiratory infections and reported reduced severity and 22% shorter duration of infection in the vitamin C supplemented group (25). Furthermore, vitamin C supplementation may be beneficial in COVID-19 patients requiring ICU admission. A meta-analysis of 12 trials with 1,766 patients showed that vitamin C supplementation shortened ICU stay by 7.8%. Another meta-analysis of eight trials including 685 patients revealed that vitamin C supplementation reduced the duration of mechanical ventilation by 14% (26, 27). A study by Agarwal et al. in Indian children (6 months–5 years) reported that children with rickets showed the best therapeutic response in healing to a combination of vitamin D and calcium, assessed biochemically and radiologically after 6 and 12 weeks of treatment (28).

A Cochrane review comprising 80 RCTs analysed the effects of zinc supplementation among children (6 months–12 years) (29). The review reported that zinc supplementation reduced diarrhoea-associated morbidity and incidence of all-cause diarrhoea. Food fortification may play a major role in decreasing the prevalence of iron deficiency. Multiple micronutrient powders (MNPs) can be considered in high-risk settings. The WHO recommends point-of-use fortification of foods with multiple MNPs in infants and children age 6 to 23 months and 2 to 12 years (10–12.5 mg elemental iron for 6 months to 4 years and 12.5 to 30 mg for 5 to 12 years, 300 µg retinol, 5 mg elemental zinc) in a population where anaemia is a public health problem (30).

Prenatal choline consumption increases neuroprotective effects in both humans and animals. Choline supplementation in the mother's and child's diets throughout the first 1000 days of life seems to promote normal brain development, enhance neural and cognitive function, and protect against neuronal and metabolic insults, particularly when the fetus is exposed to alcohol. (31).

According to a systematic risk assessment, the safe dose of lutein is 20 mg/day. Eye is an extension of the neural system, and lutein has a potential role in cognition. Evidence showed that positive association between lutein, zeaxanthin, and childhood cognition (32). Haber and Heuberger evaluated four RCTs for the effects of xanthophyll supplementation on visual development in premature infants (<33 weeks gestational age), out of which two RCTs supplemented 0.5 ml per day dosage of 0.14 mg lutein and 0.005 mg zeaxanthin via enteral feeds (maternal milk, preterm formula). Results showed that the supplemented group had reduced incidence of retinopathy of prematurity (ROP) (33).

Nutritional supplementation and multiple micronutrient powders

Nutritional supplements can help children from developing countries boost their early development and overall growth, including cognition (34).

Several strategies exist to address micronutrient malnutrition in low- and middle-income countries, including targeted modification and point-of-use fortification with MNPs (10). However, clinicians often face challenges during decision-making for nutritional supplementation due to the lack of detailed literature describing the exact role of each nutrient in various health conditions and, more importantly, the dosage considerations. Moreover, as much as a clinician's knowledge of nutrients and the potential benefits of dietary supplements is crucial, it is often limited, as noted by Karbowonik et al (35). Typical micronutrient malnutrition prevention interventions include: exclusive breastfeeding for the first six months of life and continued breastfeeding until the child is two years old, dietary diversification to have foods high in absorbable vitamins and minerals, fortification of staple and complementary foods, and vitamin and mineral supplementation (36).

Despite the well-established benefits of supplementing with one, two, or multiple micronutrients, implementation has been hindered by the lack of supply, low coverage, inadequate healthcare provider communication and support, poor adherence to dosing regimens, an absence of clear benefit, apprehensions about perceived adverse effects, possible dose-related side effects, and safety concerns (30). In order to solve these limitations, 'at-home' or 'point-of-use' food fortification with MNPs was developed as an alternative to regular iron supplementation for iron and other micronutrient delivery through foods. MNPs for children aged 6 to 23 months are typically single-dose packets of dry vitamin and mineral powder that parents or caregivers mix into any semisolid food just before eating (30). MNPs are not designed to substitute meals or breast milk, and they do not dissolve well in liquids. When MNPs are correctly mixed into semisolid food and used, the food's colour, flavour, or taste should not alter. MNP does not necessitate any changes to traditional supplemental feeding practices, as long as the complementary foods are semi-soft and not highly watery. In children aged 6 to 23 months, MNPs support and encourage optimal baby and young child feeding behaviours (30).

The difficulties in formulating effective nutrition guidelines in children

Unique challenges in India with economic transitions

Despite triple the rate of stunting reduction in the previous decade, India still has the world's largest proportion of undernourished. The World Bank believes India cannot compete in the future economy if 40% of its workforce are stunted. The Global Hunger Index (GHI) ranked India 103rd out of 119 countries in 2018. Our current healthcare system is ill-equipped to manage this new policy challenge of overnutrition. Infectious diseases have quickly given way to non-communicable diseases in recent decades (NCDs). NCDs demanded a scientific solution. NCDs include cancer, diabetes, heart disease, stroke, and others. Overweight and obesity have arisen in India in the last decade, adding to the illness load. A 2018 study of 6–19-year-olds from rural and urban schools found one in nine youngsters were overweight. It is vital to recognise that undernutrition still persists. Obesity is a major policy concern. With the decline in undernutrition comes an increase in overweight and obesity. The percentage of overweight or obese women (15-49) increased from 13% to 21%, and males from 9% to 19%. M.B.I. grew from 20.5 in 2005-06 to 21.9 in 2015 (37, 38).

The way forward

The health system must be reoriented to focus on reproductive/child health and communicable diseases through vertical interventions (37). Consolidating and expanding the focus on millennium development goals (set forth by united nations) conditions is necessary, but so is focusing on preventive and promotive health needs within a strategic model and tailored sub-district interventions (37).

Summary

Diet is critical for human growth, particularly in case of infants and children. A proper diet is essential for healthy growth since it ensures an adequate intake of macronutrients and micronutrients, among other things. Micronutrients are essential for proper growth in the paediatric population, particularly zinc, iron, vitamin D, and folic acid. Nutritional supplements are important for children as they may either complement or substitute nutrients obtained from regular food sources. However, the challenge lies in knowing the appropriate nutrient dosages, their benefits, preventing overuse, and identifying appropriate target population.

Table 1: Estimated Average Requirements in Indians (EAR) and Recommended Dietary Allowance in Children 1-18yrs and ≥ 4yrs

Nutrient	Age group	EAR (ICMR)(6)	RDA (ICMR)	Age group	RDI (FDA)(7)
Vitamin A	1-9yrs 10-18yrs	180-290μg/d 360-480μg/d	390-630μg/d 770-1000μg/d	1–3yrs ≥4yrs	300μg/d 900μg/d
Vitamin D	1-18yrs	400IU/d	600IU/d	1–3yrs ≥4yrs	15IU/d 20IU/d
Vitamin B1 Thiamine	1-9yrs 10-18yrs	0.6-1.0mg/d 1.3-1.9mg/day	0.7-1.1mg/d 1.5-2.2mg/d	1–3yrs ≥4yrs	0.5mg/d 1.2mg/d
Vitamin B2 Riboflavin	1-9yrs 10-18yrs	0.8-1.3mg/d 1.6-2.5mg/d	1.1-1.6mg/d 2.1-3.1mg/d	1–3yrs ≥4yrs	0.5mg/d 1.3mg/d
Vitamin B3 Niacin	1-9yrs 10-18yrs	6-10mg/d 12-19mg/d	7-11mg/d 15-19mg/d	1–3yrs ≥4yrs	6mg/d 14mg/d
Vitamin B6 Pyridoxine	1-9yrs 10-18yrs	0.8-1.3mg/d 1.6-2.5mg/d	0.9-1.5mg/d 2-3mg/d	1–3yrs ≥4yrs	0.5mg/d 1.7mg/d
Vitamin B9 Folic acid	1-9yrs 10-18yrs	97-142μg/d 180-286 μg/d	120-170μg/d 220-340μg/d	1–3yrs ≥4yrs	150μg/d 400μg/d
Vitamin B12 Cobalamin	1-18yrs	1-2μg/d	1.2-2.2μg/d	1–3yrs ≥4yrs	0.9μg/d 2.4μg/d
Vitamin C Ascorbic acid	1-9yrs 10-18yrs	24-36mg/d 45-70mg/d	30-45mg/d 55-85mg/d	1–3yrs ≥4yrs	15mg/d 90mg/d
Vitamin E				1–3yrs ≥4yrs	6mg/d 15mg/d
Vitamin K				1–3yrs ≥4yrs	30mg/d 120mg/d
Calcium	1-9yrs 10-18yrs	400-500mg/d 650-850mg/d	500-650mg/d 850-1050mg/d	1–3yrs ≥4yrs	700mg/d 1300mg/d
Magnesium	1-9yrs 10-18yrs	73-144mg/d 199-367mg/d	90-175mg/d 240-440mg/d	1–3yrs ≥4yrs	80mg/d 420mg/d
Iron	1-9yrs 10-18yrs	6-10mg/d 12-18mg/d	8-15mg/d 16-32mg/d	1–3yrs ≥4yrs	7mg/d 18mg/d
Zinc	1-9yrs 10-18yrs	2.8-4.9mg/d 7-14.7mg/d	3.3-5.9mg/d 8.5-17.6mg/d	1–3yrs ≥4yrs	3mg/d 11mg/d
Iodine	1-9yrs 10-18yrs	65mg/d 70-100mg/d	90mg/d 100-140mg/d3	1–3yrs ≥4yrs	90mg/d 150mg/d
Protein	1-9yrs 10-18yrs	0.6-1mg/d 1.3-1.9mg/d	12.5-23g/d 32-55g/d	1–3yrs ≥4yrs	

EAR-Estimated Average Requirement, FDA- Food and Drugs Administration, ICMR – Indian Council of Medical Research, RDA- Recommended dietary allowance, RDI- Reference Daily Intake

Table 2: Acceptable Macronutrient Distribution Ranges (AMDR) as Percent of Energy

Nutrient(9)	Age group	AMDR
Protein	1-18yrs	5-15 %E
Total fat (8)	1-2yrs 3-18yrs	30-40%E 25-35%E
n-6 PUFA	1-18yrs	4-10%E
n-3 PUFA	1-18yrs	0.5-1%E
Carbohydrate	1-2yrs 3-8yrs	40-60%E 45-65%E

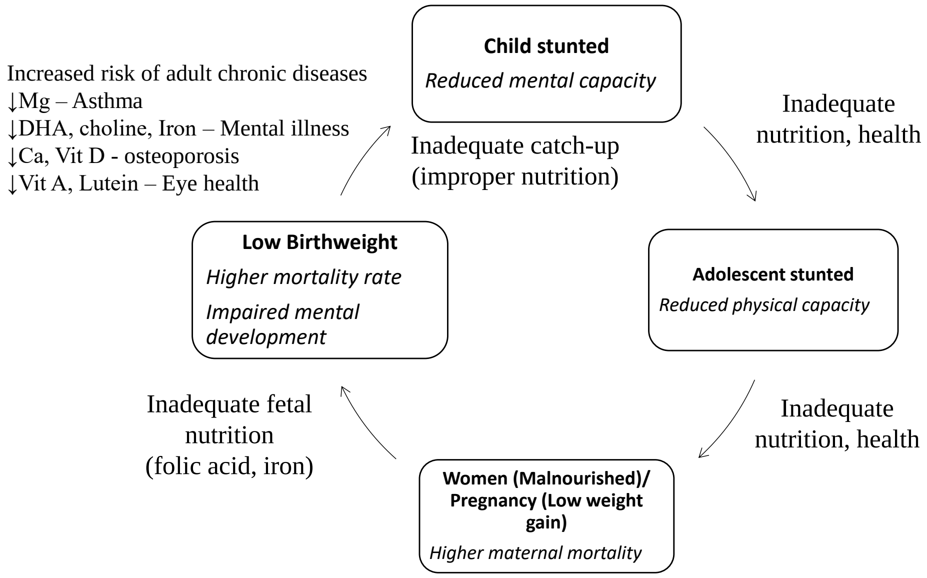
%E= Percent of energy, n-6= Omega 6, n-3= omega 3

Table 3: Nutrients - Dietary Sources, Biological role and Deficiency States

Nutrient	Dietary Source	Biological role	Clinical Deficiency
Protein	Eggs, seafood, meats and poultry, nuts, beans	Skeletal growth, cellular integrity, wound healing	Stunting (0–2yrs), wasting (0–5yrs), underweight*, malnutrition*, Kwashiorkor (0–5yrs)
Calcium	Milk, yogurt, cheese, spinach	Skeletal growth, bone remodelling, Bone and teeth mineralisation	Hypocalcaemia*, osteopenia*, osteoporosis*
Magnesium	Green vegetables, legume seeds, nuts, beans	Cofactor for enzymes involved in energy metabolism, protein synthesis, muscle and nerve function, blood pressure regulation	Neurologic and neuromuscular defects*, anorexia*, lethargy*, muscular weakness* **Supplementation benefit:** Asthma*, cardiovascular health*
Iron	Meat, seafood, nuts, beans, fortified grains	Oxygen transport, physical growth, neurological development	Iron deficiency anaemia*, irreversible effects on psychomotor skills and cognition (0–5yrs)
Zinc	Whole grains, pulses, legumes, chicken	Wound healing, immune function, protein synthesis	Impaired immune function*, diarrhoea (0–10yrs), loss of appetite
Vitamin A	Fish, meat, liver, egg, dairy products, fruits and vegetables	Cellular maintenance and repair, vision, immune response, reproduction, antioxidant activity	Night blindness (2–6yrs), xerophthalmia
Vitamin D	Fish, oils, salmon, liver, Skin exposure to UV light	Calcium absorption, bone growth and remodelling	Rickets in Children (2–6yrs) and osteomalacia in adults
Vitamin E	Vegetable oil, nuts, seeds, leafy vegetable	Antioxidant properties	Peripheral neuropathy*, ataxia*, immune response impairment*, age-related macular degeneration*, cystic fibrosis*
Vitamin K	Sprouts, cabbage, plant oils and margarine	Blood clotting and Protein synthesis	Haemorrhage*
Vitamin B1 (Thiamine)	Bread, grains, cereals, fortified food, whole grain products	Neuronal function and macronutrient metabolism	Beriberi*, infantile beriberi (1–4 months), Wernicke – Korsakoff syndrome (45–65yrs)
Vitamin B2 (Riboflavin)	Milk, bread, fortified cereals	Ocular function, antibody and RBC formation, mucosal maintenance	Oral-ocular-genital syndrome*
Vitamin B3 (Niacin)	Fish, poultry, meat, bread and fortified cereals	Macronutrient metabolism, glycogen synthesis	Pellagra (20–50yrs)
Vitamin B5 (Pantothenic acid)	Oats, potato, beef, chicken, liver, cereals	Energy metabolism Antibody, corticosteroid and cholesterol synthesis	GIT disturbances, Hypertension#, Hypersensitivity#, Neurological disorders#
Vitamin B6 (Pyridoxine)	Fortified cereals, bananas	Fat and protein metabolism, Hb synthesis, DNA and RNA synthesis. Neuronal function, Electrolyte balance, tryptophan to niacin conversion	Paraesthesia, convulsions in infants, hypochromic anaemia and glossitis **Benefits:** normal brain development (0–5yrs)
Vitamin B7 (Biotin)	Vegetables, liver, egg yolk	Energy metabolism, fatty acids and glycogen synthesis	Conjunctivitis*, dermatitis*, CNS abnormalities*
Vitamin B9 (Folic acid)	Leafy vegetables, nuts, fortified enriched cereals	Cell division and growth, RBC, WBC maturation, folic acid metabolism	Macrocytic anaemia*
Vitamin B12 (Cobalamin)	Fish, meat, poultry and fortified cereals	Iron absorption Protein and lipid metabolism Neuronal function, DNA & RNA synthesis and RBC maturation	Macrocytic anaemia – Iron deficiency anaemia, Paraesthesia*
Vitamin C (Ascorbic acid)	Citrus fruits, potatoes, tomatoes, strawberries, cabbage, spinach	Acts as coenzyme, Wound healing Corticosteroid synthesis Iron absorption	Scurvy (all ages, more common in 6–12 months), gum inflammation*, dyspnoea*, fatigue*, anaemia*
DHA (Docosahexaenoic Acid)	Seafoods, Chia seeds, Walnuts, Flax seeds	Optic nerve and brain tissue development	Cognition (0–10yrs), vision impairment (0–10yrs)
Choline	Eggs, Soy, Chicken, Almonds	Neuronal development, cell membrane development	Neural tube development (0-10yrs)
Lutein	green leafy vegetables, egg yolks	Eye development, cognitive development	Retinopathy of prematurity (ROP) (early fetal development), age-related macular degeneration*

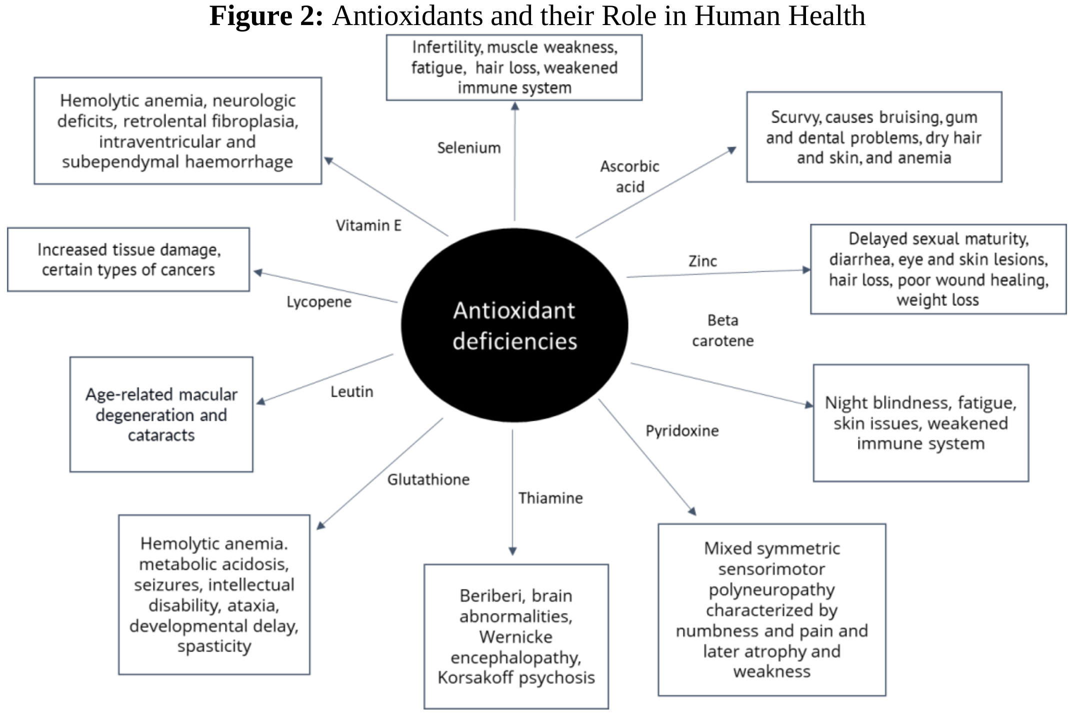
*all ages; #≥12yrs. (39). Age ranges have been compiled from standard WHO definitions and other published sources.

Figure 1: Early Life Nutrition and its Impact in Adult Hood



Adapted from: Lassi Z, et al. Child and Adolescent Health and Development. 3rd edition. Available from: https://www.ncbi.nlm.nih.gov/books/NBK525242/ doi: 10.1596/978-1-4648-0423-6_ch11

Figure 2: Antioxidants and their Role in Human Health



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