Assessing and Improving Childhood Nutrition and Growth Globally

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KEYWORDS

• Anthropometry • Overweight • Obesity • Micronutrient malnutrition • Infant feeding • Inflammation • Food security • Preschool children

KEY POINTS

- Linear growth faltering is the most common measurement used to assess child growth and affects numerous neurodevelopmental outcomes, such as cognition and motor skill development.
- Breastfeeding is a critical component of child nutrition with substantial health benefits. Improved breastfeeding practices could reduce child death, improve maternal health, and reduce the noncommunicable disease burden.
- Dietary diversity is a proxy for diet quality; measuring and improving diet quality deserves greater attention globally. Resource-constrained and resource-rich environments share a high prevalence of childhood obesity.
- Consequences of poor infant and maternal nutrition affect society through reduced capacity for work, diminished earnings, and stymied development.
- There are numerous proven interventions to alleviate malnutrition and optimize child growth and development that, when integrated with disease reduction interventions, will yield maximum effectiveness.

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INTRODUCTION

Nutrition Is the Foundation of Child Health and Well-Being

Improving maternal and child nutrition is central to global development goals and reducing the noncommunicable disease burden.[1,2] Undernutrition, characterized by poor growth and micronutrient deficiencies, is responsible for a substantial burden of mortality and loss of disability-adjusted life-years in children under 5 years of age.[3,4] In fact, approximately one-half of all childhood deaths globally are caused directly or indirectly by malnutrition.[1] Neurodevelopment and productivity also require adequate nutrition and are associated with linear growth and nutrient intake early in life.[5,6]

The first thousand days encapsulates the time from conception to when a child turns 2 years old and is when consequences of malnutrition are thought to be irreversible.[4] Robust observational studies report that poor linear growth at age 2 is associated with lower earning, less schooling, and a greater chance of living in poverty compared with children who grow normally.[4,7] Although the process of becoming malnourished often starts in utero, the consequences of poor nutrition extend across the life cycle and also into future generations.

The Etiologies of Malnutrition are Multifactorial and Interrelated

There are multiple, overlapping causes of malnutrition including individual or patient-level factors, community-level factors, and conditions at the societal level (**Fig. 1**).[8] Given the interrelated causes of malnutrition, no single "magic bullet" intervention exists to eradicate it. Subtypes of malnutrition include growth faltering, overweight and obesity, and micronutrient malnutrition, also known as "hidden hunger"; these conditions often coexist and are considered a double or triple burden of malnutrition.[3] At the basis of nutrition is food, which constitutes much more than nutrients and includes the culture and ecology surrounding food patterns and availability, as well as the individual ability to use food via ingestion, absorption, utilization, and excretion. Child nutrition is unique, in that requirements change rapidly alongside the demands for tissue accrual. Given that intake in children is often demand driven, once a child is malnourished, it may be difficult to reverse.

Malnutrition Remains Widespread Globally

Chronic malnutrition or stunting affects more than 160 million children, the global prevalence of obesity in children is approximately 13%, and 43% of preschool children live

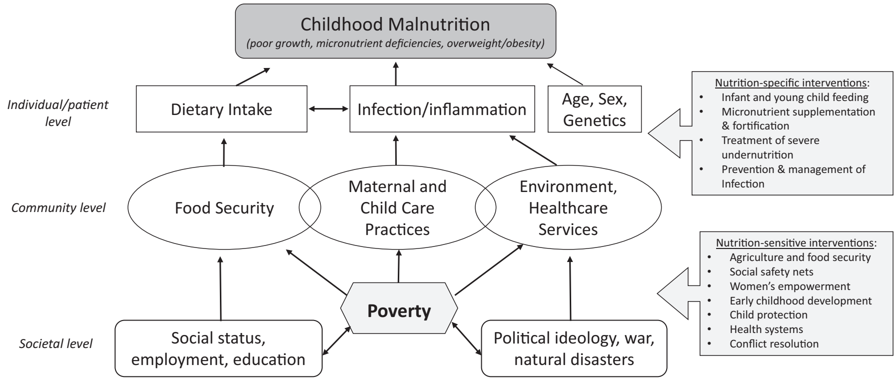

Fig. 1. Conceptual framework for major causes of child malnutrition and evidence-based interventions. (*From* Suchdev PS. What pediatricians can do to address malnutrition globally and at home. Pediatrics 2017:139(2); with permission.)

with anemia.[1,9] There is significant regional variation among these figures, and some regions face all 3 nutritional challenges. We are approaching 10 years since the 2008 *Lancet* series on Maternal and Child Undernutrition stated that "Nutrition is a desperately neglected aspect of maternal, newborn and child health"[10] and the progress is not sufficient. The 2013 *Lancet* series revised the title from Undernutrition to Nutrition, introducing overweight and obesity as malnutrition with global scale.[1] In this review, we summarize recent evidence on child growth and nutrition and present opportunities to act both at the individual (clinical) and population (public health) levels.

ASSESSMENT OF CHILDHOOD NUTRITION

Assessment of Growth

Anthropometry is the assessment of physical size and tissue density to assess body composition, and poor growth is defined by statistical comparisons of anthropometric measurements to sex-specific population reference growth curves. The primary anthropometric indices used to define malnutrition are underweight (below –2 standard deviations from median weight for age of reference population), stunting (below –2 standard deviations from median height for age of reference population), and wasting (below –2 standard deviations from median weight for height of reference population).[11] In children 2 years and older, body mass index for age can be used to classify children as overweight or obese. Overnutrition often coexists with micronutrient deficiencies,[1] especially when energy-dense, nutrient-poor foods dominate the diet. Additional anthropometric measurements that may be used include head circumference (to track brain growth), mid-upper arm circumference (to identify severe acute malnutrition in community settings), and skinfold assessment of fat mass and dual-energy x-ray absorptiometry to assess body composition.

Considerable effort went into standardizing anthropometric measurements and ensuring a globally representative sample of healthy, breast-fed infants to generate the World Health Organization (WHO) Child Growth Standards,[11] which provides a global yardstick for growth assessment. In contrast, the Centers for Disease Control and Prevention growth reference charts, developed in 2000, were based on a nonrepresentative sample of predominately formula-fed children in the United States.[12] Individual- or population-level anthropometric data can be plotted and analyzed using software available from the WHO (www.who.int/childgrowth/software) or Centers for Disease Control and Prevention (www.cdc.gov/epiinfo).

Although severe malnutrition, categorized as marasmus (severe wasting) and kwashiorkor (malnutrition with edema), may have distinctive clinical manifestations, physical examination and laboratory features of severe malnutrition are generally not reliable. Thus, anthropometric measurements by trained personnel should be emphasized for the identification of malnutrition.

Assessment of Micronutrient Status

Assessment of micronutrient status is more challenging than assessment of growth, because biological indicators of nutrition typically require blood collection and access to a laboratory. Collection of biomarkers is often expensive, invasive, and logistically cumbersome in a most population settings. In clinical settings, some nutritional biomarkers are not reliable at diagnosing individual status and therefore are only beneficial in representative population-based sampling. For example, WHO recommends median urinary iodine concentration to monitor population iodine status, but does not recommend urinary iodine to detect individual status because its concentration varies between days and from hour to hour.[13] Similarly challenging is the assessment of zinc status, which fluctuates based on time since last meal and with diurnal variations; further, specimens can be easily contaminated, therefore requiring sophisticated collection techniques.[14] In general, nutrient biomarker concentrations change with age, are affected by physiologic factors, and can differ by gender. For example, inflammation can directly affect concentrations of nutrients, because some nutrient biomarkers are themselves acute phase proteins (eg, serum ferritin and retinol). The confounding effects of inflammation can result in an incorrect diagnosis of malnutrition in individuals, as well as overestimation or underestimation of the prevalence of deficiency in a population. Strategies to account for inflammation when interpreting nutritional biomarkers have been proposed but have yet to be endorsed by the WHO.[15,16] With the increasing burden of noncommunicable diseases, accounting for inflammation may be even more important for estimating micronutrient malnutrition.

The Biomarkers of Nutrition for Development (BOND), the Inflammation and Nutrition Science for Programs and Interpretation of Research Evidence (INSPIRE), and Biomarkers Reflecting Inflammation and Nutrition Determinants of Anemia (BRINDA) projects, organized by the National Institute of Child Health and Human Development and other partners, have compiled evidence to guide researchers, clinicians, and policymakers on micronutrient assessment in various settings.[17] Given the high cost and challenge of collecting biomarkers, cost-effective nutrient biomarkers are needed, as well as those that better measure changes in exposure or status in response to nutrition interventions.[18]

Assessment of Diet

Dietary assessment methods are required to more comprehensively assess child nutrition. Dietary assessment at the population level relies heavily on assumptions and estimated availability rather than intake, and is based on national food supply data. Individual-level food availability and dietary intake patterns are more challenging to assess at scale. Food frequency questionnaires, weighed food records, and 24-hour dietary recall methods are available to assess individual consumption patterns, but have not been considered practical for national surveys. However, tablet-based data collection has improved the potential to collect quantitative dietary data at scale using camera-enabled technologies to identify foods and estimate portion sizes that can be linked directly to nutrient databases.[19] The challenge that single-day dietary intake records are not sensitive for assessing usual intakes of nutrients,[20] and confounding factors such as seasonality, will continue to complicate dietary assessment. As such, dietary diversity is a metric that is useful for assessing nutrient adequacy, although it too has limitations because most dietary diversity tools do not capture quantity.[21–23] Another noteworthy limitation of dietary diversity tools is that they often do not account for nutrient-poor, energy dense foods, such as sugar-sweetened beverages, that contribute to obesity. Dietary assessment of women and young children is now standardized across settings based on extensive research by the WHO and the Food and Nutrition Technical Assistance (FANTA) project.[24,25]

Assessment of Infant Feeding Practices

In 2008, the WHO published 3 technical documents pertaining to global infant and young child feeding practices: definitions, measurements, and country profiles.[25] More recently, the infant and young child feeding framework has been expanded to include maternal nutrition. These population-level indicators allow for standardized assessment and monitoring, as well as providing a basis for formulating program targets. The practice of these recommended infant feeding practices are correlated with better growth and child survival.[26] In addition to exclusive breastfeeding for the first 6 months of life, continued breastfeeding is recommended for up to 2 years of age.[25] The introduction of foods at 6 months of age to complement breastfeeding is assessed by feeding frequency and dietary diversity. The 7 food groups considered in the WHO infant and young child feeding package for infants 6 to 24 month old are (1) grains, roots, and tubers, (2) legumes and nuts, (3) dairy, (4) flesh foods, (5) eggs, (6) vitamin A–rich fruits and vegetables, and (7) other fruits and vegetables. Consuming at least 4 of these 7 food groups in the previous 24 hours is considered sufficient as a population indicator for dietary diversity.[27] The cutoff of 4 food groups was chosen because it requires that either an animal source food or a high-protein source (legumes or nuts) would have been included in the child's diet. Other context-specific health eating indices have been developed, but there are no global dietary guidelines outside of recommended nutrient intakes. The recommended nutrient intakes for infants and young children are often set as adequate intakes, which means that there is insufficient evidence to designate a recommended allowance for this age group. A lack of evidence for recommended feeding practices of children 2 to 5 years of age persists throughout the school age period.

NONNUTRITIVE CONSIDERATIONS FOR CHILD GROWTH AND DEVELOPMENT

The interactions between child nutrition and growth, infection, and neurodevelopment are complex and multidirectional.[18] Chronic and acute infection impairs growth and may cause micronutrient deficiencies through reduced appetite and increased losses via diminished absorption and direct loss through diarrhea or vomiting, as well as the heightened metabolic requirements associated with infection.[28] Further, malnutrition inhibits the body's defense system to fight infections.[29,30] Nonnutritive factors known or suggested to affect child growth and development include environmental exposures, the gut microbiota, maternal characteristics, home environment, and toxic stress, and have been reviewed recently.[18]

Environmental Exposures

Mycotoxins are a form of fungal food contamination, the most common being aflatoxins, that are implicated to negatively affect child growth.[31–33] A primary concern with aflatoxin exposure is the ubiquitous nature of this contamination in regions that are already plagued with food insecurity and poor crop diversity.[34] Maize and groundnuts are 2 staple food items that are commonly infected with aflatoxins. Groundnuts, along with milk powder, is a vital component of ready to use therapeutic food, and the control of aflatoxins could enable safe locally available production of ready to use therapeutic food for community-based treatment of malnutrition.[35]

Environmental enteropathy, also called tropical enteropathy, is an obscure condition of blunted intestinal villi that is also implicated in poor growth and nutritional status.[36] The reduced mucosal surface area prevents optimal nutrient absorption. Environmental enteropathy is difficult to characterize, and the current array of biomarkers include those that identify intestinal inflammation, such as myeloperoxidase and alpha-1 antitrypsin.[37] Ongoing studies assessing environmental enteropathy and growth show a negative relationship.[38–40] For example, in a pilot study in Bangladesh, cleaner household environments were associated with less environmental enteropathy and improved growth.[41] The widespread environmental contamination and resulting inflammation that prevents optimal child growth suggests that more programs promoting clean environments are warranted.

Gut Microbiota

The emerging field of discovery surrounding the gut microbiome is enabling powerful investigations to elucidate the mechanisms between poor environmental health and growth faltering. The Breastmilk, Gut Microbiome, and Immunity (BMMI) project is focused on understanding the role of nutrient intake in early life on microbiome diversity and subsequent health conditions.[42,43] Experimental investigations of gut microbiota and human milk oligosaccharides reveal unique patterns of diversity among the microbial and oligosaccharide communities when comparing healthy and malnourished infants.[44,45]

Maternal Characteristics

Maternal stature is a primary predictor of child length for age.[1] Well-nourished mothers are more likely to give birth to children who do not suffer from intrauterine growth restriction or are small for their gestational age.[1,46] Maternal illness during pregnancy is also a negative predictor of child growth,[31] similar to maternal depression on child growth[47] and neurodevelopment.[48–50] Maternal depression can affect child behavior and academic functioning at all stages, starting prenatally through adolescence. There is also limited evidence suggesting that maternal time constraints detract from child nutrition.[51] Improved child feeding has been documented through more paid leave, allowing parents to best feed their children.[52]

Home Environment

The home environment is a critical component of childhood growth and developmental success.[5] Although specific nutrient deficiencies can be tied to developmental delays, such as iodine or vitamin B_{12}, adequate and appropriate stimuli are also required for children to reach their development potential.[5,53] Underlying drivers of adequate intake of nutrient-rich foods, like access to animal source foods and the likelihood of having books at home, for example, may be economically driven.[54] However, the level of nurturance and stimulation provided within a child's environment can have a significant effect on a child's development. There is growing evidence that interventions focused on parenting and responsive stimulation can positively affect parent–child interactions and child outcomes in low- and middle-income countries.[55–57]

Toxic Stress

Toxic stress refers to the stress response resulting from "strong, frequent, or prolonged activation of the body's stress response systems in the absence of the buffering protection of a supportive adult relationship" and is considered the result of cumulative adverse childhood experiences, including such things as abuse and parental alcoholism, divorce, and mental illness.[58] There are now extensive data demonstrating the deleterious effects of toxic stress on children's health and development, summarized in a 2012 technical report for the American Academy of Pediatrics.[58]

CLINICAL MANAGEMENT AND POPULATION INTERVENTIONS TO ADDRESS MALNUTRITION

Evidence-based interventions for child malnutrition can be generalized as nutrition specific (address immediate causes, often at the individual level) or nutrition sensitive (address underlying causes, often at the community or societal level; see **Fig. 1**). Effective nutrition-specific interventions include management of severe protein-energy malnutrition using the WHO 10-step approach and ready-to-use therapeutic foods, promotion of breastfeeding and appropriate complementary feeding practices, and micronutrient supplementation and food fortification.[59] Nutrition-sensitive interventions include conditional cash transfer programs, promoting the education of girls and the social status of women, health care infrastructure improvements, and focusing on nutrition when planning agriculture. The impact of these interventions results in hundreds of thousands of lives saved annually, and most of these interventions are considered highly cost effective.[59–62] In addition to saving lives, the impact of these interventions on child growth, improved micronutrient status, and developmental potential are summarized in **Table 1**.

Breastfeeding Promotion and Complementary Feeding Education

Infant feeding promotion is an evidence-based intervention known to improve child growth and optimize development.[63,64] Breastfeeding is advantageous for the mother and the child, and comes at a relatively low cost captured by increased maternal caloric needs and time to feed the child. Mothers benefits from a reduced risk of cancer and children incur the nutritive and nonnutritive benefits of breastmilk as well as increased intelligence and reduced burden of infections.[65] Maternal nutrition influences milk composition, specifically with respect to the fat composition of breastmilk, which accounts for approximately 50% of the kilocalories in breastmilk. Moms with low-fat diets generate fat de novo or recruit stored lipids. De novo generation of fat for breastmilk results in short to medium chain fatty acids. Long chain polyunsaturated fatty acids are known to be antiinflammatory agents and are most easily recruited into breastmilk from maternal dietary sources.[66,67] There is wide regional variation of breastmilk fatty acid composition, which impacts infant health and development, more dramatically among preterm infants.[68] The fat composition of breastmilk and general dietary nutrient composition of complementary foods predisposes children to a myriad of health outcomes. Optimal complementary feeding guidance promotes dietary diversity and improves feeding frequency, and can be done at a low cost, promoting women in communities to share knowledge and gain employment as health workers, which also plays a positive role in women's empowerment.[69,70] Knowledge that infant nutrition alters the risk for noncommunicable diseases and that obesity is more common among nonbreastfed infants demands that child nutrition be prioritized.[71]

Maternal Nutrition

It is negligent to discuss infant growth and nutrition without discussing maternal health and nutrition as well. Maternal diet influences fetal development,[72,73] can affect methylation patterns that lead to epigenetic programming,[74] and maternal nutritional status is correlated with breastmilk nutrient composition.[75] Often overlooked, the maternal diet is also important for maternal health itself, which is paramount for children's well-being. Mothers tend to be the primary caregiver to children in most settings. Maternal nutrition directly affects child nutrition from conception throughout breastfeeding, and maternal and child dietary patterns are correlated at the time of introduction of household foods,[76] further emphasizing the importance of maternal nutrition on child nutrition and growth.

Summary and Call to Action

Evidence indicates that supoptimal nutritional and environmental conditions during the developmental window of time from conception up to 5 years of age can have lifelong lasting consequences.[4] As a scientific community and engaged citizens, it is our duty to advocate for improved child and maternal nutrition. There is evidence of

Table 1
Summary of effects of evidence-based nutrition interventions on child nutrition and growth

Intervention	Estimated Effect on Child Micronutrient Deficiency or Morbidity	Estimated Effect on Child Survival, Growth, or Development
Preconception nutrition		
Multiple micronutrient supplementation	No difference in anemia and iron deficiency anemia[80]	11%–13% reduction in low birthweight and SGA births[59,80]
Iron and folic acid supplementation	Reduced anemia by 27%; increased hemoglobin 4.6 g/L and serum ferritin 8.3 µg/L (mean differences)[81]	19% reduction in low birthweight[82]
Calcium supplementation	No data available	24% reduction in preterm births[83]
Iodine supplementation or fortification	73% reduction in cretinism; 10%–20% increase in developmental scores (among iodine deficient populations)[84]	No data available
Infant and young child feeding		
Early initiation of breastfeeding promotion	No data available	44%–45% reduction in all-cause and infection-related neonatal mortality[85]
Breastfeeding promotion	No data available	Increased exclusive breastfeeding by 90% for 1–5 mo[86]
Complementary feeding promotion	No data available	Increased height (HAZ standard mean difference 0.22) among food secure populations; reduced stunting by 32% in food insecure populations
Micronutrient supplementation and fortification		
Iron supplementation	Reduce anemia by 49% and iron deficiency by 76%	No effect on growth Increased mental development score (0.30, 0.15–0.46)
Vitamin A supplementation	Reduce all-cause mortality by 24% (0.17–0.31)	No effect
Zinc supplementation[87]	Reduce diarrhea by 13% and pneumonia by 19%	Improved mean height of 0.37 cm
Multiple micronutrients	Reduction of iron deficiency anemia by 57% and retinol deficiency by 21%[88]	Increased length (0.13, 0.06–0.21)
Home fortification	Reduce anemia by 31%; Reduce iron deficiency by 51%[89]	No effect[89]

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Table 1
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Intervention	Estimated Effect on Child Micronutrient Deficiency or Morbidity	Estimated Effect on Child Survival, Growth, or Development
Treatment of severe undernutrition	No data available	RUTF compared with standard care has similar effect on mortality but faster rate of weight gain[59]
Prevention and management of infection		
WASH (water, sanitation, hygiene)	Reduce diarrhea by 48%[90]	Increase in HAZ score 0.08[91]
Deworming	No effect on anemia[59]	No effect on growth[59]
Malaria prevention	Reduce anemia by 29%[92]	Reduced malaria-attributable mortality by 55% in Africa[93]

Abbreviations: HAZ, height for age z-score; RUTF, ready to use therapeutic food; SGA, small for gestational age.

effective interventions, both at the individual and population levels, and the cost is modest relative to other diseases that have a comparable morbidity and mortality burden. For example, every $1 invested in child micronutrient interventions can yield $30 in benefits.[77] It is unclear why the demonstrated benefits from nutrition-specific and nutrition-sensitive interventions have not generated more demand for implementation of such interventions at scale. This must change.

The importance of nutrition for child growth and development is not an international topic—it is global[1]; for example, the United States has a large burden of childhood obesity[78] and food insecurity, which disproportionately affect children. There is some evidence of improved dietary quality and improved rates of childhood obesity through federal social assistance programs, such as the Special Supplemental Nutrition Program for Women, Infants, and Children.[79] Interventions to improve maternal and child nutrition need to receive ample support to ensure the health and well-being of future generations, which will benefit the greater society as a whole.

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