Chapter

Malnutrition: Current Challenges and Future Perspectives

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Abstract

Achievement of good nutrition is important in Universal Healthcare; hence, all stakeholders should be updated regarding management of malnutrition and challenges encountered, especially in resource-constrained societies of the world. Coexistence of multiple predisposing factors of malnutrition therefore compounds its diagnosis and management. It is of paramount importance therefore that the vulnerable population should be provided with adequate knowledge to alleviate the nutritional challenges they encounter. Capacity building of the healthcare personnel that are entrusted to serve such vulnerable societies should be improved appropriately. Healthy nutrition policy makers, implementers, and evaluators in all healthcare sectors should be conversant with new developments in management of malnutrition and challenges including those encountered in case studies, such as one recently encountered in Kenya, during the management of isoniazid induced pellagra (IPT) in a TB patient also on antiretroviral therapy. Food fortification, nixtamalization, provision of ready-to-use therapy foods (RUTFs), and innovative lipid-based nutrient supplements are relatively new areas whose nutrition policy makers, implementers, and evaluators should be well updated in. As part of nutrition optimization among those at risk, the nonadherence to exclusive breastfeeding for at least 6 months, which globally remains unacceptably high (59%), should urgently be addressed through appropriate and widespread counseling.

Keywords: breastfeeding, challenges, counseling, fortification, innovative lipid-based nutrient supplements, malnutrition, nixtamalization, nutrition, optimization, universal healthcare

1. Introduction

Malnutrition has been clearly described by the World Health Organization, among other entities dealing with the professional aspects of the subject matter [1, 2]. The nutritional imbalance can be classified in various ways, especially for purposes of proper and adequate management. Currently, the categories of malnutrition include undernutrition, overweight, and obesity, among others that will be substantiated shortly. The study of malnutrition, especially in developing countries, will remain important for a long time to come. This is because vulnerable communities, families, and/or individuals therein are likely to be adversely affected, with consequences of morbidity and mortality. Significantly large proportions (about 50%) of children aged five and below die from malnutrition and its complications, including infections. The severity, prevalence, and incidence of such infections may delay recuperation. Stunted growth and impaired cognitive and other aspects of child development may adversely affect learning of children during their first few years (more so the first 1000 days of life).

2. Worrying global prevalence trends of malnutrition

According to 2019 statistics from the World Health Organization and UNICEF [1–3], malnutrition is cosmopolitan, and its prevalence remains unacceptably high, consequently impacting negatively on the lives of the affected children. Approximately one third of women of reproductive age had anemia, while obesity affected a slightly higher proportion (39%) of the world's adult population. Underweight babies constitute a further 20 million, despite a noted slow decline in stunted growth. In 2018, just over a fifth (21.9%) of the world's children aged five had stunted growth, despite its overall global prevalence decline from 32.5% during the period between the years 2000 and 2018. During the same period, the population of stunted children decreased in terms of millions (from 198.2 to 149.0). Of this proportion, nearly 40% lived in South Asia, and a similar proportion lived in Africa south of Sahara (SSA), although an alarming proportional increase has been noted from west and central Africa (22.4 million to 28.9 million). Earlier in 2010, 49 million children aged five and below were wasted, while a further 17 million suffered from severe wasting thus translating to 7.3 and 2.4%, respectively. One worrying global trend is the fact that about 45% of mortality among children aged five and below is linked to malnutrition, the bulk of these occurring in low- and middle-income countries. A further global trend is that 528 million (29%) of reproductive-age women are vulnerable to anemia occasioned by inadequate dietary iron supplementation. In the low and middle - income Countries, the rates of childhood obesity and overweight were on the rise, estimated to nearly threefold rise in prevalence during the period between the years 2000 and 2018 alone, in Eastern Europe, Central Asia, the Middle East, and Northern Africa. The prevalence in these regions ranges between 8.8 and 11.2%, respectively. Eastern and south-east Asia, the Pacific, and northern Africa account for more than a third of the world's overweight children. The gender distribution of these statistics tends to show higher stunting rates among boys than girls. This is thought to be due to the fact that boys have relatively higher risk of low birth weight and preterm birth than girls. These disparities were noted to be prevalent in Latin America, South-ease Asia, and the Caribbean. More attention should then be placed on these regions by those dealing with intervention measures. WHO [3] report also cites that those who are at risk of malnutrition include infants, children, women, and adolescents and that optimization of nutrition early in life (specifically within the first 1000 days of life) will ensure the child gets the best possible start in life with its life-long benefits. Unfortunately, the nonadherence to the recommended prevalence of breastfeeding practices among many societies of the world remains relatively low and worrying, since only 41% (hence 59% non-compliance) of infants aged 6 months or less were exclusively breastfed and only 45% were continually breastfed for at most 2 years in 2017 [4].

3. Factors contributing to good nutrition

Before we consider the factors that predispose to malnutrition, let us first discuss the factors that contribute to good nutrition. These factors play an important role, especially in places where the resources are inadequate for the affected society and/ or families [5]. Many of these factors are intertwined, especially in developing countries, where small-scale subsistence farming is practiced. The most notable of these are good agricultural practices, good and vibrant economy, healthy enabling environment, healthy social and family life, good antenatal and perinatal care, and early screening and control of preventable diseases. We shall now revisit each of these factors.

3.1 Good agricultural practices

Parents and household heads need to take responsibility in ensuring good agricultural practices (especially clearing farm land at the right time, planting sufficient good crops, using irrigation and fertilizer where necessary, getting appropriate advice from agricultural extension workers, harvesting at the right time, and safe storing the food to avoid losses through pests, a good transport and distribution system to get enough good food to all regions) are done appropriately. Chronic and irresponsible alcoholism by those charged with providing for the family, for example, may lead to poor (or inadequately productive) agricultural practices that will lead to loss of family income, poverty, and family neglect and may lead to malnutrition, among other health challenges in the family. Improvement of nutrition and prevention of malnutrition require energetic and cooperative efforts directed toward all these factors.

3.2 Good and vibrant economy

Those in influential leadership and governance of societies should on priority basis ensure there is a good economy in place. This should guarantee sufficient resources allocated to support adequate food and fuel/energy, health and education, and good education, among other society needs. Unfortunately, this is not always the case in many parts of the world, especially in developing countries.

3.3 Healthy enabling environment

Each country should ensure there is equitable availability and distribution of safe and sufficient water for drinking, cooking, cleaning, and other uses. Environmental sanitation and sewage treatment and management should also be appropriate. If this kind of environment is lacking, then the affected society will be vulnerable to many health problems, including related nutrition challenges.

3.4 Good education

Provision of appropriate and adequate knowledge on good nutrition and child health to the societies is critical. In most developing countries, this can effectively be done by those charged with the responsibility of disseminating such knowledge to schools, families, and any other modes of communication to large populations. Through good health education, the right attitudes and practices that promote good nutrition to the most vulnerable groups (especially children and mothers) will be guaranteed.

3.5 Healthy social and family life

Dissemination of adequate knowledge on family planning matters, at the right time to the right audience, is important. The right size of and the availability of adequate resources to the family and the presence of a health social environment in a family are paramount. This will ensure adequacy of food and attention to the whole family, especially younger children who usually need more care. Arrangements to ensure adequate resources for food, shelter, and other needs are maintained even if either or both parents have to work and a caretaker has to look after the children in their absence. Good supervision to ensure children get adequate and appropriate food should be in place at all times (at home, in day-care centers, and other such places); otherwise, some children might become malnourished. Care for children from broken or incomplete families directly affects nutritional status, especially if the social integration and communal care are lacking.

3.6 Good antenatal and perinatal care

Pregnant mothers require good antenatal care, especially to ensure good nutrition during pregnancy in order to avoid giving birth to low birth weight babies and to prevent intrauterine growth retardation and prematurity.

3.7 Early screening and control of preventable diseases

Immunization and vaccinations done appropriately at the right time to the right people will ensure early detection and prevention of diseases. Early screening for congenital malformations that interfere with child's eating or food utilization (such as cleft lip/palate, congenital hypertrophic pyloric stenosis) can alleviate related health problems and their management.

4. Factors predisposing to malnutrition

Globally, inadequate food intake is the most common cause of malnutrition: [5, 6]. In developing countries, inadequate food intake may be due to poverty, insufficient, or inappropriate food supplies or early weaning and premature stopping of breastfeeding. Ignorance about the need to have a balanced diet (and lack of adequate knowledge about the appropriate food and the right quantities needed by each family member) and ignorance about the importance of breastfeeding may be important contributing factor(s) in some places, especially if those endowed with the responsibility of disseminating the right knowledge fail to do it appropriately. Psychosocial issues, such as premature death of a breastfeeding mother, deliberate maternal deprivation from whatever reason may also contribute to childhood malnutrition. Single mothers (due to death of a spouse, separation, or divorce) may also face the challenge of premature stoppage of breastfeeding, owing to the fact that such mothers have to constantly provide food and other needs for the family, without the help of a spouse. This challenge might also contribute to maternal deprivation of adequate food to the baby, abuse of the rights toward the baby, especially if the baby was born out of unplanned pregnancy. The introduction of breast milk banks has alleviated this problem in certain places, but adequate health education of the safety and convenience of this approach has not yet been fully embraced culturally by many societies. The fear of disease transmission through breast milk remains a hindrance of new approaches of providing breast milk to babies whose mothers are missing or are not able to produce enough breast milk. In some areas, cultural and religious food customs may play a role. For example, ignorance of what constitutes a balanced diet can contribute to malnutrition. Consequently, certain families might sell most food sources they produce and actually need for the family, in order to buy larger quantities of food supplies they do not actually need. Poor family planning is a major problem in some cultures, especially where polygamy and bearing many children are encouraged, without due regard to limited available resources to support the families. Poor personal and environmental hygiene, due to inadequate sanitation, may aggravate situation by encouraging food contamination during food handling, preparation, and consumption. Consequently, the affected individuals will suffer from inherent risks of dangerous infectious diseases that will increase nutritional losses and/or altered metabolic demands. This scenario is likely to lead to repeated infections if the infrastructure lacks well-maintained sewage and sanitation facilities and/or supply of adequate clean water. Constant or frequent exposure to infection/infestation with intestinal and other worms such as hook worms and fish tape worms, among others will also predispose to nutritional iron deficiency anemia. Many people living under deplorable health conditions will also be exposed to many other parasites, including ascariasis, which contribute to food deprivation.

Chronic disease conditions and illnesses are important etiological factors of malnutrition: [5, 6]. This is especially more so in developed countries. People with chronic illnesses (especially children) are at relatively higher risk of nutritional problems. Some of the contributing factors include the following: chronic illnesses are frequently associated with loss of appetite and therefore intake of inadequate food. Some chronic illnesses are also associated with increased metabolic demands, hence increasing caloric needs. Any chronic illness that adversely affects the liver, pancreas, or intestines has the potential of adversely impairing food digestion and absorption. Other chronic illnesses that are associated with malnutrition include surgical diseases (such as cleft lip and/or palate, chronic hypertrophic pyloric stenosis), malignancies, congenital heart diseases, chronic renal failure, chronic bowel inflammatory diseases (such as ulcerative colitis), neuromuscular diseases, and cystic fibrosis, among others. Furthermore, risk of nutritional deficiency may be due to prematurity, failure to thrive for whatever cause, and exposure to toxins *in utero* (e.g., alcohol intake during pregnancy).

People with multiple food allergies (especially children) may become malnourished, due to challenges of dietary restrictions: [5, 6]. People with active allergic symptoms may have increased calorie and protein needs. This is partly because their state of morbidity predisposes them to lack of appetite during the time of ill-health and therefore without extra dietary supplements they might become malnourished. Furthermore, the allergy to certain foods denies them the benefit of the nutrients found in the food they are allergic to. If there is lack of appropriate dietary substitute, then the affected individuals will become malnourished with time.

5. Classification of malnutrition

Malnutrition can be classified into different categories [3, 7], namely, undernutrition, overnutrition, micronutrient-related malnutrition, severe acute (SAM), moderate acute (MAM), and global acute malnutrition (GAM), respectively. The assessment of body mass index (BMI) is one of the major ways of differentiating some of these categories. Details of BMI will be given later in the chapter.

Undernutrition consists of stunting, wasting, underweight, and micronutrient deficiencies. Stunting refers to a situation whereby children have a lower than normal height-for-age. Wasting refers to lower than normal weight-for-height, while underweight refers to lower than normal weight-for-age. Micronutrient deficiency refers to inadequate intake of vitamins and minerals. In more technical terms, the World Health Organization [3] defines these terms as follows. Underweight is defined as weight for age < -2 standard deviations (SD) of the WHO Child Growth Standards median. Stunting is defined as height for age < -2 SD of the WHO Child Growth Standards median. Wasting is defined as weight for height < -2 SD of the WHO Child Growth Standards median. The predisposing factors to some of these are known. Low birth weight is associated with intrauterine growth retardation or restriction, prematurity, or both. This situation is likely to ultimately predispose to poor health in the vulnerable societies. These situations, in addition to aggravating growth and cognitive and chronic disease development in adulthood, also predispose to morbidity and mortality, especially of neonates. Low-birth-weight infants are 20 times more likely to die of these than healthier infants.

Overnutrition comprises obesity and overweight. These are important because they are increasingly associated with lifestyle disorders, notably diabetes mellitus and cardiovascular diseases capable of complicating to stroke and even cancer that are responsible for morbidity and mortality from noncommunicable diseases. In more technical terms, overweight is defined as weight for height $> +2$ SD of the WHO Child Growth Standards median. Whereas undernutrition is prevalent among societies with inadequate food and the other predisposing factors already described, overnutrition is conversely associated with more affluent societies who tend to live more sedentary lives and can afford more palatable and fast-prepared junk food. These types of food stuffs are relatively cheap and readily available to a large section of the world population. No wonder the upsurge in related nutritional disorders. Variations in nutritional status may also be seen in individual families in a given community.

Micronutrient-related malnutrition occurs due to inadequate intake of vitamins and minerals. Micronutrients enable the body to produce enzymes, hormones, and other essential substances needed for proper growth and development of the human body. Among the micronutrients most essential are iodine, vitamin A, and iron. The deficiency of these micronutrients paused major health threats especially among children and pregnant women from low socioeconomic status.

The following categories are mainly for purposes of management of malnutrition [8]. Moderate acute malnutrition (MAM) refers to weight-for-height z-score (WHZ) between -2 and -3 or mid-upper arm circumference (MUAC) between 115 and <125 mm. Severe acute malnutrition (SAM) refers to WHZ < -3 or MUAC <115 mm, or the presence of bilateral pitting edema, or both. Global acute malnutrition (GAM) refers to the combination of MAM and SAM and is used as a measurement of nutritional status at a population level and as an indicator of the severity of an emergency situation. The prevalence thresholds for severity of malnutrition among children aged five and below are described elsewhere [5, 9–11].

6. Historical background and importance of classifying malnutrition

Part of the documented historical background of the classifications of malnutrition dates back to 1956, when Gómez and Galvan studied the factors they thought were associated with death among malnourished children Mexico City [12]. Initially, this classification was based on first, second, and third degrees, respectively [13]. The degrees were based on weight below a specified percentage of median weight for age [9] According to this classification, the risk of death increases with increasing degree of malnutrition [13]. An adaptation of Gomez's original classification is still used today. Whereas this modification provides a way of comparing malnutrition within and between populations, this classification has been criticized as too arbitrary and does not consider overweight as a classification of malnutrition, apart from the fact that height alone may not be the best indicator of malnutrition. Children who are born prematurely may be considered short for their age even if they have good nutrition [14]. Nevertheless, the criticism led to the establishment of a new classification of malnutrition by John Conrad Waterlow [15]. Waterlow classification therefore combines weight-for-height (indicating acute episodes of malnutrition) with height-for-age to show the stunting that results from chronic malnutrition [16]. One advantage of the Waterlow classification over the Gomez classification is the fact that weight for height can be examined even if ages are not known [15]. The World Health Organization has since modified some of these classifications [9].

7. Importance of malnutrition classification in children

Stunting, wasting, underweight, and overweight indicators are important for assessing nutritional imbalance resulting in undernutrition among children, according to the World Health Organization [12]. As far as child growth is concerned, it is internationally recognized as an important indicator of health in populations. It is also important as indicator for nutritional status. The cumulative effects of malnutrition and the consequent complications among children are reflected by the percentages of children with stunting (low height for age) from and even before birth. The degree of stunting can therefore be interpreted as an indicator for the existence of poor environmental conditions that have the potential of restricting child growth. The proportion of underweight and/or wasted children also indicates acute weight loss, stunting, or both. Hence, it may be difficult to interpret 'underweight' because it is a composite indicator. Thus, underweight, even in its mildest form, indicates increased risk of childhood mortality, and this risk increases among severely underweight children. Inadequate food and recurrent childhood infections also have a tendency to increase the risk of mortality among affected children. Stunting predisposes to poor child performance in school and also to delayed developmental milestones and decreased intellectual development in terms of capacity. Childhood wasting also predisposes to immunosuppression, subsequently leading to increased susceptibility to infections.

Childhood obesity may precede the same in adulthood. Overweight and obesity (especially in adolescence and childhood) increase the risk of developing short- or long-term health problems, notably cardiovascular disorders and diabetes mellitus. Also, among the risks are musculoskeletal disorders (e.g., osteoarthritis) and malignancies of the breast, colon, and/or endometrium. The assessment of nutritional status of a given population is an important indicator for moderate and/or severe malnutrition.

8. Importance of malnutrition classification in women

Chronic malnutrition may adversely affect the growth of bones in girls, such that those affected are likely to have abnormal short stature, with relatively smaller pelvis than women with normal growth. Thus, the affected women may get complications during child birth, which might cause obstructed labor that might be dangerous for the baby, the mother, or both. Other birth-related complications of such mothers include the birth of babies with lower weight than normal (low birth weight babies), retarded intrauterine growth, and short stature later in adult life. Their likely general maternal morbidity may also adversely affect quality of healthcare of the mother and baby during pregnancy.

8.1 Anthropometric measurements

The major mode of assessment of nutritional status of gravid women and children is by the use of anthropometry (the process by which anthropometric measurements are serially taken). The measurements have been developed and improved over time. These measurements taken quantitatively and involve measurements of muscle girth, bulk, and sometimes muscle power and tone if other inherent nervous system problems are suspected. Bone length and density as well as quantity of adipose tissue may also be measured. However, the main anthropometric measurements are those of weight and height, and from these two, the body mass index (BMI) may be calculated. Also important are the measurements of head circumference, waist, hip, and limb circumferences as well as the thickness of skin folds. As already discussed in the previous section, such measurements are important in assessing the nutritional status of children and pregnant mothers. For children, the individual measurements done, respectively, determine whether or not each child is normally growing, is stunted, is wasted, or is underweight. For pregnant women, the measurements will determine timely interventions of correcting the malnutrition and even the mode of delivery (normal or assisted vaginal delivery or by Cesarean section). The measurement will therefore also determine the place and cost of delivery if specialists may be required during and after delivery. The type of nutritional follow up will also be determined by the serial quantitative anthropometric measurements. In more sophisticated healthcare set-ups such as in developed countries [17–19], anthropometry is not only vital for timely and appropriate diagnosis of abnormalities such as microcephaly, macrocephaly, anencephaly, diabetes mellitus, hypertension, and other lifestyle-related illnesses, but it also enables early diagnosis of metabolic syndrome and dyslipidemia, among others. Furthermore, the measurements are helpful in initial assessment and progress of physical fitness of athletes and even the general population [18, 19] and for monitoring of nutritional status of children and pregnant mothers [20, 21] by the use of newer scientific methods in comparison to conventional ones.

However, there are situations whereby such measurements are discouraged. These include individuals who have undergone limb amputation or those with Plaster of Paris. Anthropometric measurements may be erroneous for those with gross abdominal obesity because of difficulties of locating important reference bony landmarks. Inexperienced personnel taking the measurements may also increase the chances of erroneous measurements.

The body mass index (BMI, which is the weight in kilograms divided by the square of the height in meters—kg/m^2) is helpful in determining the classification of obesity, overweight, or underweight in both children and adults. The range of measurements calculated in this manner, in relation to given limits for the normal and abnormal values, will determine whether or not an individual is healthy in terms of BMI. Normal weight BMI range is generally between 18.5 and 24.9. Moderate to severe thinness in adults is indicated by BMI < 17.0, whereas a BMI < 18.5 is an indication of underweight. Individuals considered overweight are those with BMI ≥ 25.0, while those considered obese have BMI ≥ 30.0. The health implications of underweight, obesity, and overweight have already been discussed in the previous section. Generally, overweight and obesity predispose to a wide range of noncommunicable diseases. Among these are malignancies of various types, musculoskeletal and respiratory disorders, gallbladder diseases, ischemic (coronary) heart disease, and associated complications such as heart attack and stroke, among others. Some of these drastically reduce the lifespan and/or quality of life of affected individuals. The significance and implications of BMI are therefore of paramount importance in public health, which cannot be anymore overemphasized.

DOI: http://dx.doi.org/10.5772/intechopen.92007

8.2 Pathophysiology of malnutrition

Malnutrition and its complications may affect virtually part of the human body basically because the energy provided by various biomolecules, vitamins, and micronutrients is essential for all physiological and biochemical functions in the body [6, 22]. Dietary deficiency of these nutrients therefore adversely affects the functioning of the body. Digestion of protein to produce amino acids is required for metabolism, enzymatic functions, and antibody production, among others. Micronutrients are required as cofactors for various metabolic functions essential for the body. When nutritional deficiency occurs, the body is forced to readjust its hormonal secretion and metabolic functions (a process known as reductive adaptation) in order to economize on the available nutrients for survival.

Among the adjustments are reduced thyroxine and insulin productions to minimize metabolic rate and increase glucose availability for generation of energy, respectively. Consequently, protein deficiency leads to impaired/arrested or failed physical growth and/or cognitive development. Immunity may also be suppressed due to relatively reduced antibody production occasioned by protein deficiency. Other immune response changes include decreased complement system and certain cytokine functioning, impaired phagocytosis due to decreased T-lymphocyte levels, loss of delayed hypersensitivity, and decreased secretion of immunoglobulin A (IgA). These are subsequently associated with increased susceptibility to a wide variety of infections. Diarrhea from the infections may further aggravate the situation by causing anorexia, decreased nutrient absorption (also due to villous atrophy that occurs especially in kwashiorkor), and direct nutrient losses, among other changes requiring increased metabolic needs of the body. In order for the body to meet its energy demands, the body resorts to breaking down stored fat and muscles, resulting in body wasting seen especially in marasmus. Other pathological changes within the brain that have been confirmed in various studies, include reduced myelination, brain neurons, weight and growth rate, thinning of the cerebral cortex, and changes in the dendritic spines in severely malnourished infants. Fatty degeneration of the liver and the heart coupled by small bowel atrophy and decreased intravascular volume may result in secondary hyperaldosteronism in some. A differential diagnosis of these changes is severe mental retardation [22].

8.3 Clinical presentation of malnutrition

Protein energy malnutrition (PEM), sometimes synonymously described as undernutrition, commonly presents with a myriad of clinical symptoms and signs [6]. The complaints elicited during history taking typically include poor weight gain, slowing of linear growth, behavioral changes such as apathy (lack of interest in surroundings), irritability, anxiety, impaired social responsiveness, and some deficits in attention. Oedema, apathy, hair and skin changes, and reduction of subcutaneous tissue are frequently observable in patients with PEM [23], and the most affected are the face, arms, legs, and buttocks. It is not unusual to find coexistence of PEM with deficiency of micronutrients, especially in developing countries. The micronutrient-deficient individuals may actually present with features resembling those of PEM. Kwashiorkor and marasmus are two forms of PEM that commonly coexist (hence known as marasmic-kwashiorkor) or may be distinct as separate clinical entities [24]. PEM may cause cognitive impairment, especially if the nutritional deficiency occurs between the third trimester of pregnancy and the first 2 years of life [25]. Iron deficiency anemia in children aged 2 years and below is likely to affect brain function as an acute and probably also as a chronic occurrence.

Similarly, the deficiency of folic acid has also been associated with defective development of neural tubes.

'Kwashiorkor', which is a Ghanaian term that means 'the sickness the older one gets when the next sibling is born', is caused by inadequate consumption of dietary protein [24]. The descriptive definition rightly identifies the fact that the older sibling is deprived of breast feeding and instead is weaned on a diet composed largely of carbohydrates and devoid of proteins [26], thus rendering the older sibling malnourished. The clinical presentation of kwashiorkor mainly includes but exclusive to oedema, apathy, failure to thrive, underweight, and hair changes. Oedema occurs due to hypoalbuminemia following decreased oncotic pressure and consequent fluid extravasation to tissues. Oedema affects the face and the upper and lower extremities and may be slight or gross (anasarca), depending on the degree of protein deficiency. The presence of ascites and pleural effusion suggests the existence of peritoneal infection with tuberculosis (TB peritonitis). Failure to thrive (underweight, usually between 60 and 80% of expected body weight or failed growth) commonly occurs and may be masked by oedema, especially in lower extremities. Unlike in marasmus, kwashiorkor presents with muscle wasting (but with retention of subcutaneous tissue). Wasting of muscles is especially seen on chest, upper arms, and gluteal area. Children with high intake of carbohydrates (hence known as 'sugar babies') but with coexisting kwashiorkor tend to have generalized puffiness and much subcutaneous fat but no skin changes. Those affected also frequently have very low albumin levels. Close observation of an affected child will typically reveal apathy (due to mental changes, making the child apathetic and miserable; hence, the child may sit the whole day without interest in food or surroundings). This is in contrast with marasmus whereby the child is extremely wasted and hungry but may even be playful and interested in surroundings. Hair changes (altered texture, loss of luster, fine, straight, soft, scarce, and easily plucked hair with color changes ranging from brown, and reddish, to gray blond or white) are observable. Skin changes are also common, depicting pigmentation or depigmentation, desquamation (flunky-paint or irregular dermatoses), or ulceration. In severe cases of kwashiorkor, the skin may resemble extensive burns over the child's legs, buttocks, and perineum. Severe cases are prone to potentially fatal hypothermia, due to decreased basal metabolic rate (BMR); hence, the skin cannot respond to a fall in environmental temperature. Hypothermia victims may die especially at night when temperature is very low. Changes in mucous membranes include angular stomatitis, cheilosis, smooth tongue, perianal ulceration, and papillar atrophy. Hepatomegaly may occur due to fatty infiltration of the liver and also may occasion by profound but potentially fatal hypoglycemia. Gastrointestinal changes include anorexia, nausea, and vomiting. Diarrhea is nearly always profused and may result in dehydration and electrolyte imbalance. Dehydration is more chemical than infective in origin. If chemical (malabsorptive) diarrhea occurs, it causes decrease in enzymes, secondarily associated with villous atrophy (the atrophied portions are the tips where lactose is absorbed, hence resulting in lactose intolerance), low proteins, and pancreatic atrophy. Lactose intolerance may also occur and may be due to failure to absorb lactose, resulting in osmotic diarrhea. Lactose in the gut also predisposes to fermentation by normal gut flora, resulting in lactic acid formation, hypoperistalsis that may aggravate diarrhea. Anemia is frequently present and tends to display dimorphic (microcytic/macrocytic hypochromic) picture. If purpura and thrombocytopenia occur, they unfortunately indicate guarded/severe prognosis if no urgent management intervention is instituted.

'Marasmus' (which means 'to waste away') is caused by combined inadequate intake of protein and energy, which causes gaunt expression, severe wasting, leaving little or no edema, minimal subcutaneous fat, severe muscle wasting, and abnormally low serum albumin levels. Metabolism in such a child is adapted to prolonged survival [24, 27]. In contrast to the situation in kwashiorkor, muscle wasting in marasmus is associated with loss of subcutaneous tissue. Marasmus in some semiliterate societies is sometimes described as 'a child with an appearance of an old man wearing an oversized coat', for lack of better description to make it better understood by those very ignorant of the dangerous situation the child is in and requiring urgent intervention. The child's interest in surroundings and playful nature is therefore deceptive. Marasmus is typically seen in places with severe famine, conflict or war-torn areas with significant food restriction, or more severe cases of anorexia [24]. A child with marasmus may be anemic, but less so than kwashiorkor and hair changes are also fewer than in kwashiorkor. Tuberculosis and other secondary coinfections may occur and should therefore be sought carefully.

Complications of malnutrition include infections, hypothermia, hypoglycemia, anemia, dehydration, electrolyte imbalance, growth retardation/failure to thrive, and thrombocytopenia/disseminated intravascular coagulopathy (DIC), among others.

8.4 Micronutrients (vitamins, minerals, and trace elements) and their toxicities

Micronutrients (vitamins, minerals, and trace elements), in addition to essential fatty acids and amino acids [28, 29], are important for health. Fat-soluble vitamins are A, D, E, and K, while B and C are water-soluble vitamins. Fat-soluble vitamins have a higher potential for toxicity than do water-soluble vitamins, owing to their ability to accumulate in the body. The most toxic are those vitamins that contain iron, especially the following acute ingestions by affected children. In the context of nutrition, a mineral is a chemical element required as an essential nutrient by organisms to perform functions necessary for life [30, 31]. Since minerals are elements, they cannot be synthesized biochemically by living organisms but are obtained by plants from soil [32]. Human beings obtain most of their minerals from eating plants and animals or from drinking water [32]. The five major minerals in the human body are calcium, phosphorus, potassium, sodium, and magnesium [30, 33]. The rest of the elements (at least 20 of them) with specific biochemical body functions are sulfur, iron, chlorine, cobalt, copper, zinc, manganese, molybdenum, iodine, and selenium, which serve as structural and functional roles and electrolytes [30, 34]. The most abundant elements in the body are oxygen, hydrogen, carbon, and nitrogen. Calcium makes up to 99% of bones and teeth and making up about 1.5% of body weight. Phosphorus makes up about two thirds of calcium and about 1% of a person's body weight, while the other major minerals (sodium, potassium, chlorine, sulfur, and magnesium) constitute about 0.85% of the body weight. Overall, the 11 chemical elements (H, C, N, O, Ca, P, K, Na, Cl, S, and Mg) constitute 99.85% of the human body, with the rest forming only 0.15% of the human body [33]. The main sources and clinical presentation of micronutrient deficiencies and toxicities are hereby tabulated (**Table 1**).

8.5 Useful investigations

Laboratory studies are done based on information from a complete history and physical examination [6]. The most helpful laboratory studies in assessing malnutrition in a child are hematological studies and laboratory studies evaluating protein status. Hematological studies should include a complete blood count (CBC) with red blood cell (RBC) indices, serum electrolytes, sedimentation rate, urinalysis, culture, and a peripheral smear. The blood tests help to exclude anemia from various nutritional deficiencies, including iron, folic acid, and vitamin B-12

Micronutrient	Functions/sources	Clinical presentation of deficiency/ toxicity
Vitamin A (Retinol)	Pro-vitamin A plant carotenoids (mainly carrots), animal products (liver, milk, kidney, fish oil), fortified foods, and drug supplements. Aids in night vision, growth. Isotretinoin (Accutane) used for the treatment of severe forms of acne, is closely related to the chemical structure of vitamin A (hence similar pharmacology and toxicity)	**Vitamin A deficiency** presents with night blindness, xerophthalmia, poor growth, and hair changes. Birth defects (when taken during pregnancy), intracranial hypertension, depression, and suicidal ideation have been reported with isotretinoin. **In acute vitamin A toxicity**, some or all of the following may be present: nausea, vomiting, anorexia, irritability, drowsiness, altered mental status, abdominal pain, blurred vision, headache, muscle pain with weakness, seizures. **In chronic vitamin A toxicity,** some or all of the following may be present: anorexia, hair loss, dryness of mucus membranes, fissures of the lips, pruritus, fever, headache, insomnia, fatigue, irritability, weight loss, bone fracture [35], hyperlipidemia, hypercalcemia [36]. Anemia, bone and joint pains, diarrhea, menstrual abnormalities, epistaxis. Vitamin A may cause increased bone resorption and promote the development of osteoporosis. **Carotenemia** (excess vitamin A intake) has no adverse consequences because the conversion of carotenes to retinol is not sufficient to cause toxicity. Carotenemia is manifested by a yellow-orange coloring of the skin, primarily the palms of the hands and the soles of the feet. It differs from jaundice in that the sclerae remain white
Vitamin D (Cholecalciferol)	Dairy products, egg yolks, liver, and fish. It facilitates calcium absorption and mobilizes calcium from bone	**Vitamin D deficiency**: Poor growth, rickets, and hypercalcemia. Place patients with vitamin D toxicity on a low-calcium diet. Consider oral calcium disodium edetate to increase fecal excretion of calcium. In cases of severe hypercalcemia, patients may require hydration, diuretics, steroids
Vitamin E (tocopherol and tocotrienol)	Vegetable oil, nuts, sunflower, wheat, green leafy vegetables, fish. It is an antioxidant and free-radical scavenger in lipophilic environments. Storage of the vitamin occurs in adipose tissue, the liver, and muscle. Vitamin E may block absorption of vitamins A and K. It also decreases low-density lipoprotein (LDL) cholesterol level at doses more than 400 IU/day	Since vitamin E may block absorption of vitamin K, a nutritional assessment for vitamin K deficiency is useful in patients who present with bleeding and a prolonged prothrombin time (PT). The effects of **acute vitamin E toxicity** include nausea, gastric distress, abdominal cramps, diarrhea, headache, fatigue, easy bruising, and bleeding—prolonged PT and activated partial thromboplastin time (aPTT), inhibition of platelet aggregation, diplopia —at dosages as low as 300 IU, muscle weakness, creatinuria. **Chronic Vitamin E toxicity** effects include all of the above, as well as suppression of other antioxidants and increased risk of hemorrhagic stroke. Vitamin E supplementation was shown to increase the risk of prostate cancer in healthy men, in the Selenium and Vitamin E Cancer Prevention Trial (SELECT) [37]
Vitamin K (phytonadione)	Produced by intestinal bacteria (vitamin K-2) and is found in green, leafy vegetables; cow's milk; and soy oil (vitamin K-1).	Vitamin E can prolong the prothrombin time (PT) by inhibiting vitamin K–dependent carboxylase, although

Micronutrient	Functions/sources	Clinical presentation of deficiency/toxicity
	Vitamin K-1 supplements are usually 2.5–10 mg. Phytonadione promotes liver synthesis of factors II, VII, IX, and X	administration of vitamin K corrects this. High doses of vitamin E increase the vitamin K requirement; coagulopathy can occur in patients who are deficient in vitamin K [38, 39] (concomitant use of vitamin E and anticoagulants can also increase the risk of bleeding complications) [38, 39]
Vitamin B	**Vitamin B-1** (thiamin): found in organ meats, yeast, eggs, and green, leafy vegetables. Vitamin B-1 supplements usually contain 50–500 mg of vitamin B-1 per tablet. This vitamin is a cofactor for pyruvate dehydrogenase in the Krebs cycle. The RDA is 1.5 mg (0.7 mg for children aged 1–4 years). **Vitamin B-2:** The RDA for vitamin B-2 (riboflavin) is 1.7 mg (0.8 mg for children aged 1–4 years). Supplements usually are 25–100 mg. **Vitamin B-3** (niacin) is found in green vegetables, yeast (pumpernickel bagels may contain 190 mg of niacin), animal proteins, fish, liver, and legumes. Supplements are usually 20–500 mg per tablet. Vitamin B-3 synthesis requires tryptophan. Niacin is converted to nicotinamide adenine dinucleotide (NAD) or nicotinamide adenine dinucleotide phosphate (NADP). NAD and NADP are coenzymes for dehydrogenase-type reactions. **Vitamin B-6** functions in protein and amino acid metabolism. Pyridoxine is the treatment of choice for isoniazid overdose. It is also used by bodybuilders, as well as for the treatment, with varying results, of the following [40]: premenstrual syndrome (PMS), Carpal tunnel syndrome, Schizophrenia, Childhood autism, Attention deficit hyperactivity disorder (ADHD). **Vitamin B-12** (cyanocobalamin), which requires an intrinsic factor for absorption, is found in milk products, eggs, fish, poultry, and meat. Supplements usually contain 25–250 mcg of the vitamin per tablet. Vitamin B-12 is a treatment of pernicious anemia and cyanide poisoning	In large doses, niacin decreases synthesis of LDL cholesterol level. The RDA is 20 mg (9 mg for children aged 1–4 years). Vitamin B-6 (i.e., pyridoxine) is found in poultry, fish, pork, grains, and legumes. Supplements usually are 5–500 mg per tablet
Vitamin C (ascorbic acid)	**Functions:** An antioxidant and reducing agent, its controversial uses include treatment of upper respiratory tract infections and cancer [41]. Supplements are usually 100–2000 mg per capsule. **Sources**: Vitamin C is found in citrus fruits and vegetables	Rebound scurvy (in infants born to women taking high doses), renal colic (nephrolithiasis), diarrhea nausea, hemolysis (if glucose-6-phosphate dehydrogenase (G6PD) deficiency is present), dental decalcification, increased estrogen levels, occult rectal bleeding
Folate (folic acid)	**Functions**: Decreases the risk of neural tube defects and may reduce serum homocysteine levels (which are a coronary artery disease risk factor). It may also have a therapeutic role as an adjuvant therapy for the treatment of methanol toxicity, since it enhances the elimination of formate. **Sources**: Folate is found in oranges and green, leafy vegetables	Glossitis, anemia (megaloblastic), and neural tube defects (in fetuses of women without folate supplementation)

Micronutrient	Functions/sources	Clinical presentation of deficiency/ toxicity
Iron	**Function**: Required for many proteins and enzymes, notably hemoglobin to prevent anemia. **Sources**: Meat, seafood, nuts, beans, dark chocolate	**Deficiency**: Iron deficiency anemia features: Fatigue, anemia, decreased cognitive function, headache, glossitis, and nail changes (koilonychia). **Toxicity**: Iron overload disorder (hemochromatosis) [42]
Iodine	**Functions**: Required for synthesis of thyroid hormones, thyroxine, and triiodothyronine and to prevent goiter. **Sources**: Seaweed (kelp or kombu), grains, eggs, iodized salt, saltwater fish	**Iodine deficiency**: Severe iodine deficiency results in goiter. Population effects of severe iodine deficiency, termed iodine deficiency disorders (IDDs), include endemic goiter, hypothyroidism, and cretinism, decreased fertility rate, increased infant mortality, and mental retardation**. Iodine excess**: Iodism, Hyperthyroidism. **Iodine toxicity**: Excessive iodine may cause hypothyroidism by feedback inhibition of thyroid hormone production and conversion of triiodothyronine (T3) to less active thyroxine (T4).
Zinc	**Functions**: Zinc is necessary for growth, DNA synthesis and normal taste perception. It also supports wound healing, immune function and reproductive health and testosterone production. **Sources**: Oysters, Red meat, poultry, seafood, whole grains, nuts and fortified cereals	**Deficiency**: Anemia, dwarfism, hepatosplenomegaly, hyperpigmentation and hypogonadism, acrodermatitis enteropathica, diminished immune response, poor wound healing. Symptoms/ signs: acne, eczema, xerosis, seborrheic dermatitis, or alopecia, oral ulceration, stomatitis, or white tongue coating. Rarely, angular cheilitis disturbed sense of smell and taste, night blindness, impaired immunity, diarrhea, anorexia; psychological disturbances: behavioral abnormalities, such as irritability, lethargy, and depression (due to impaired cognitive functions), delayed growth, teratogenic effects, hypogonadism, delayed puberty, and sexual maturity. **Toxicity**: nausea, vomiting, abdominal pain, diarrhea, flu-like malaise, lowering of good HDL cholesterol (increased risk of heart disease). Decreased taste function (hypogeusia), copper deficiency (associated with sideroblastic and iron deficiency anemia and neutropenia), immunity suppression
Copper	**Functions**: It helps maintain a healthy metabolism, promotes strong and healthy bones and ensures the nervous system works properly. Required component of many redox enzymes, including cytochrome c oxidase. **Sources**: Liver, seafood, oysters, nuts, seeds; some: whole grains, legumes	**Copper deficiency**: fatigue and weakness (due to iron deficiency anemia; also copper is required to generate ATP), frequent sickness (due to neutropenia), weak and brittle bones (osteoporosis), learning and memory difficulties (e.g., Alzheimer's disease), walking difficulties, increased sensitivity to cold, pallor and premature gray hair (due to melanin underproduction), vision loss. **Copper toxicity [33]**: nausea, vomiting (food or blood), diarrhea, stomach pain, black, "tarry" stools, headaches, dyspnea, cardiac arrhythmias, low blood pressure, coma, jaundice, kidney damage, liver damage
Magnesium	**Function**: Required for processing ATP and for bones, energy transfer, storage, and	**Deficiency:** Hypomagnesemia (earliest: neuromuscular and neuropsychiatric

Micronutrient	Functions/sources	Clinical presentation of deficiency/toxicity
	use; protein, carbohydrate, and fat metabolism; maintenance of normal cell membrane function; and the regulation of parathyroid hormone (PTH) secretion. Systemically, lowers blood pressure and alters peripheral vascular resistance. **Sources**: Spinach, legumes, nuts, seeds, whole grains, peanut butter, avocado	disturbances, common being hyperexcitability, neuromuscular irritability, including tremor, fasciculations, tetany, Chvostek and Trousseau signs, and convulsions, apathy, muscle cramps, hyperreflexia, acute organic brain syndromes, depression, general weakness, anorexia, vomiting; osteoporosis, nephrolithiasis—urinary stones; diabetes mellitus often associated). **Toxicity/excess**: Hypermagnesemia (neuromuscular symptoms—deep tendon reflex attenuation, facial paresthesias, muscle weakness—especially respiratory, causing apnea; conduction system symptoms)
Phosphorus	**Functions**: A component of bones, cells, in energy processing, in DNA and ATP (as phosphate) and many other functions. **Sources**: Red meat, dairy foods, fish, poultry, bread, rice, oats. In biological contexts, usually seen as phosphate	**Deficiency:** Hypophosphatemia (most asymptomatic; severe/chronic forms have weakness, bone pain, rhabdomyolysis, and altered mental status)**. Toxicity/excess:** Hyperphosphatemia (asymptomatic; may have hypocalcemia—muscle cramps, tetany, and perioral numbness or tingling; uremia—fatigue, shortness of breath, anorexia, nausea, vomiting; sleep disturbances)
Potassium [43]	**Function**: A systemic electrolyte and is essential in co-regulating ATP**. Sources:** fruits, vegetables, beans and nuts, sweet potato, tomato, Irish potato	**Deficiency:** Hypokalemia (features of underlying cause; weakness and fatigue; muscle cramps and pain (severe); worsening diabetes control or polyuria; palpitations; psychological symptoms (e.g., psychosis, delirium, hallucinations, depression); cardiac arrhythmias; respiratory failure). **Toxicity/excess:** Hyperkalemia: (asymptomatic; nonspecific; frank muscle paralysis, dyspnea, palpitations, chest pain, nausea or vomiting, paresthesias)
Sodium [44, 45]	**Function:** A systemic electrolyte and is essential in co-regulating ATP with potassium. **Sources:** Table salt (sodium chloride, the main source), sea vegetables, milk, and spinach	**Deficiency:** Hyponatremia: (nausea and malaise, mild reduction in the serum sodium, lethargy, decreased level of consciousness, headache, and (if severe) seizures and coma). **Toxicity/excess**: Hypernatremia (elderly, diabetic, inadequate care; lethargy, confusion, abnormal speech, irritability, seizures, nystagmus, myoclonic jerks, tachycardia, oliguria, weakness)
Chlorine [46, 47]	**Function:** Needed for production of hydrochloric acid in the stomach and in cellular pump functions. **Sources:** (with sodium): beans, lentils, dairy products, seafood, banana, prune, carrot, orange	**Deficiency:** Hypochloremia [fluid loss, dehydration, weakness/fatigue, dyspnea, diarrhea or vomiting (fluid loss)]. **Excess:** Hyperchloremia (fluid retention, hypertension, muscle weakness, spasms, or twitches, irregular heart rate, confusion, difficulty concentrating, and personality changes, numbness or tingling, seizures and convulsions)
Calcium [48, 49]	**Function:** Needed for muscle, heart and digestive system health, builds bone, supports synthesis and function of blood cells. **Sources:** Dairy products, eggs,	**Deficiency:** Hypocalcaemia (acute symptoms: multiple CVS effects causing syncope, chronic heart failure, and angina; neuromuscular symptoms: numbness,

Micronutrient	Functions/sources	Clinical presentation of deficiency/ toxicity
	canned fish with bones (salmon, sardines), green leafy vegetables, nuts, seeds, tofu, thyme	tingling, tetany, bronchospasms, dysphagia, voice changes (laryngospasms)). **Excess/toxicity:** Hypercalcemia (nausea, vomiting, alterations of mental status, abdominal or flank pain, constipation, lethargy, depression, weakness and vague muscle/ joint aches, polyuria, polydipsia, nocturia, headache, confusion)
Manganese [50–52]	**Functions:** A cofactor in enzyme functions; antioxidant properties in mitochondria; has role in metabolism of carbohydrates, amino acids, cholesterol & gluconeogenesis; formation of health cartilage & bone; increases collagen production (improved wound healing). **Sources:** Whole grains (cereals, brown rice), legumes, seeds, nuts, leafy vegetables, tea, coffee, pineapples, sweet potatoes	**Deficiency:** Manganese deficiency (characterized, more so in animals than humans, by impaired growth, impaired reproductive function, skeletal abnormalities, impaired glucose tolerance, and altered carbohydrate and lipid metabolism; humans develop bone demineralization, decreased serum cholesterol, rashes). **Toxicity/excess:** Manganism (psychiatric and motor disturbances from chronic exposure; neurological symptoms including: reduced response speed, irritability, mood changes, and compulsive behaviors; more protracted exposure produces idiopathic Parkinsonism-like disorder, Lou Gehrig's disease and multiple sclerosis)
Chromium [53–55]	**Function:** Chromium can improve insulin sensitivity and enhance protein, carbohydrate, and lipid metabolism, although its mechanisms of action and quantity needed not well-defined. **Sources**: Broccoli, grape juice (especially red), meat, whole grain products, processed meats, high-bran breakfast cereals, coffee, nuts, green beans, broccoli, spices, and some brands of wine and beer	**Deficiency:** Chromium deficiency (due to total parenteral intake/I-V fluids: symptoms and signs include severely impaired glucose tolerance, weight loss, peripheral neuropathy, and confusion). **Excess:** Chromium toxicity [**Acute exposure**: Intense G.I.T irritation/ ulceration and corrosion, epigastric pain, nausea, vomiting, diarrhea, vertigo, fever, muscle cramps, hemorrhagic diathesis, toxic nephritis, renal failure, intravascular hemolysis, circulatory collapse, liver damage, acute multisystem organ failure, and coma/death, depending on the dose (Hay, Derazon et al., 2000; Lewis, 2004; Meditext, 2005). **Chronic esxposure**: Repeated skin contact causes incapacitating eczematous dermatitis with edema; conjunctiva and mucous membrane irritation, nasal ulcers and perforations, keratitis, gingivitis, periodontitis and lung cancer (Cohen and Costa, 1998; Lewis, 2004; Meditext, 2005); bronchitis, sinusitis, nasal polyps; liver and kidney toxicities (Rom, 2007)]
Selenium [35, 40, 56, 57]	**Function**: Essential to activity of antioxidant enzymes like glutathione peroxidase. Also plays role in thyroid hormone metabolism, DNA synthesis, reproduction and protection from infection. **Sources**: Brazil nuts, Sea foods (especially fish—yellow-fin tuna fish, cod, red snapper, and herring), organ meats/ beef & poultry, grains, dairy products, eggs, rice, beans, whole-wheat bread	**Deficiency:** Selenium deficiency [characterized by male/female infertility, muscle weakness, fatigue, mental fog, alopecia, and weakened immunity). People at risk of deficiency: thyroid (goiter), dialysis, HIV, malignancy, Crohn's and Grave's disease patients, pregnancy]. **Excess:** Selenosis [characterized by diarrhea, fatigue, hair loss, joint pain, nail discoloration or brittleness and nausea. Symptoms persisting 90 days or longer

Micronutrient	Functions/sources	Clinical presentation of deficiency/ toxicity
		include fingernail discoloration and loss fatigue and hair loss]
Cobalt (cyanocobalamin) [58, 59]	**Functions:** Its part of vitamin B-12 (required in the synthesis of vitamin B-12; hence needed for erythropoiesis; also essential for maintaining the nervous system. Cobalt is also part of the biotin-dependent Krebs-cycle, for glucose/energy production. **Sources**: Animal products containing vitamin B-12 (milk products, eggs, fish, poultry, and meat)	**Deficiency:** Pernicious anemia (B-12 deficiency): numbness, Fatigue, and tingling sensation, later, decreased nerve function. **Excess:** Cobalt poisoning (characterized by toxic cardiomyopathy, polycythemia, leading to congestive cardiac failure). Poisoning can follow excessive inhalation, ingestion or direct body contact. It can also cause goiter or inactivity of thyroid and hyperglycemia. Cobalt poisoning has been reported after hip-replacement surgery if cobalt/ chromium was used during the surgery, as a metal-to-metal hip implant). Cobalt is contraindicated in people with Leber's syndrome, a rare eye condition, should not take it without medical advice; otherwise, it can result in blindness
Molybdenum [58]	**Functions**: It is a cofactor for several enzymes that breakdown xanthine, hypoxanthine, and sulfite. They also break down and detoxify many harmful compounds. It is affected by the amount of copper and sulfate in the diet. **Sources:** Legumes, whole grains (cereals), nuts, and leafy vegetables	**Deficiency:** Very rare. **Excess:** Molybdenum toxicity (gout-like syndrome, characterized by high levels of molybdenum, uric acid, and xanthine oxidase in blood). Molybdenum is contraindicated in patients with gallstones or kidney disease. Molybdenum supplements can cause a copper deficiency, by displacing copper from body tissues

Table 1.
Deficiencies and toxicities of micronutrients, including vitamins, minerals, and trace elements.

deficiencies, which are measured by assessing serum albumin, retinol-binding protein, prealbumin, transferrin, creatinine, and BUN levels. Others include retinol-binding protein, prealbumin, and transferrin determinations that are much better short-term indicators of protein status than albumin. A better parameter to use in the field is serum albumin, since it has a longer half-life. In children who have a history of adequate food intake and signs/symptoms of malnutrition, focus is made toward identifying the cause of malnutrition. Stool specimens should be obtained if the child has a history suggestive of presence of worms or other parasites or circumstances that predispose to malnutrition. Other useful tests include thyroid functions or sweat chloride tests, liver function and triglyceride tests (for suspected liver disease), zinc levels (especially if chronic diarrhea is present), blood and urine sugar levels (to rule out diabetes mellitus), and coeliac serology tests, among other tests, depending on suspected cause(s). Nutritional assessment parameters such as height and weight (for BMI), MUAC, head circumference in children aged three and below, and others that are recognized according to the WHO standards are also done.

8.6 Treatment and management principles and prevention of malnutrition

The principles laid down for the management of malnutrition are generally applied [6]. These include the need for multi-disciplinary professional approach for specific, supportive, and preventive management. Specific and supportive treatments will largely depend on the classification of malnutrition encountered, while preventive measures will also depend on avoiding the prevalent cause and the predisposing factors encountered by those affected. Specific treatments will focus on the actual cause(s) of the malnutrition diagnosed after thorough evaluation of history, physical examination, and various investigations. These include provision of specific dietary food measured out depending on their preparation or manufacture, in addition to appropriate food supplements that may be fortified or not, depending on the prevailing cultural and socioeconomic practices encountered. Supportive management entails the need to initially manage life-threatening anemia, hypoglycemia, and/or hypothermia if these are found. Zinc [60, 61], folic acid, iodine, and vitamins A and D, among other supplements may also be given if indicated. Any other micronutrient deficiencies must be corrected, especially for children who still require to growth and development. Prevention measures largely address the need to avoid the predisposing factors of malnutrition from recurring in future, through appropriate health education and follow-up assessment schedules and programs. Promotion of breastfeeding, appropriate weaning practices, and age-appropriate nutritional counseling are strongly recommended in developing countries where there are major challenges in getting safe alternatives for human milk. The need to address emerging trends of food fortification, Ready-to-Use Therapeutic Foods (RUFT) [62], and other related issues is also important. Supplementations that are beneficial for pregnant mothers worldwide need special appropriate attention [63, 64]. Nutritional researches, with a view to addressing emerging and/or re-emerging nutritional challenges, such as those associated with antiretroviral and pellagra (IPT) [65] should also be encouraged.

8.7 Food fortification and nixtamalization

Food fortification [66], described as the supplementation of one or more components to improve the benefits from the natural or artificial food products [67], has received much professional and cosmopolitan attention. Food fortification is either voluntary or mandatory. Voluntary fortification gives food manufacturers the option to add minerals, vitamins, or both, to the food to be fortified, provided there is compliance with the laid down rules and regulations by Food and Drug Administration (FDA). On the other hand, mandatory fortification provides no option to do the same, in order to ensure that the significant public health need(s) is/are addressed adequately. Some of the mandatory fortifications achieved in the past include that of global iodized salt, vitamins A and D, zinc, folic acid, and iron and fortification of several B vitamins (thiamin, riboflavin, and niacin) to baking flour in certain countries, such as the United States during the 1940s onward, among many others. Such approaches by the FDA have successfully seen the reduction of neural tube defects (by 1998) among other problems. Food fortification as the major approach to the treatment of malnutrition is considered more cost effective and enables improvement of health achievable over a relatively shorter time than other forms of food aid. Many countries continue to identify their own fortification requirements and the approaches to address them; hence, fortification programs should be developed in this manner to address other common nutritional deficiencies. Iron deficiency, among many others, still needs to be addressed locally and globally. Despite the progress in food fortification, there are still major challenges to be overcome to ensure that malnutrition is well managed. However, precautions need to be taken to avoid over-fortification, by ensuring that minimum and maximum daily dietary requirements for fortification are met for each type of fortification. To achieve these, global authorities, including the World Health

Organization among others that adhere to evidence-based data for such important decisions, should lead the way.

Although nixtamalization (the process for the preparation of maize/corn or other grain, by soaking and cooking them in an alkaline solution—usually lime water or wood ash lye then washed and hulled to soften them) is an ancient practice of improving the nutritional value of maize and other grains such as sorghum, some of its benefits (e.g., the ability to remove between 97 and 100% of aflatoxin from contaminated maize) [66] may continue to encourage the practice in places where maize is the staple food. The fact that pellagra was in the past found to be endemic in poor populations that used maize in southern parts of the United States during the early period of the twentieth century [68] does not rule out the possibility of the same happening in contemporary times within the developing world. It is encouraging to note that pellagra was nearly eliminated in the developed world after fortification of wheat flour was achieved [69]. However, it might remain a challenge in places where such fortification has not been fully achieved, a likely scenario in many developing countries. The fact is that case studies such as the one described in Kenya recently (although this was a patient on antiretroviral therapy and prone to drug induced pellagra on treatment for tuberculosis) [65] may suggest the need to explore the possibility of existing pellagra due to niacin deficiency and in the absence of nixtamalization—a process that is rarely practiced in some societies, despite the need for it in some. In this regard perhaps, nixtamalization may still have a place in modern societies, especially in the developing world, and may need to be explored and improved. This has in the past been done with some benefits of reducing pellagra, improving availability of dietary calcium, copper, and zinc and removal of mycotoxins (aflatoxin) that is produced by *Fusarium proliferatum* and *Fusarium verticillioides* in certain places [70]. However, other unexplored effects (beneficial and adverse) may need to be investigated through further research.

8.8 Innovative lipid-based nutrient supplements and ready-to-use therapeutic foods (RUTF)

In addition to food fortification already described, innovative lipid-based nutrient supplements have also been introduced to alleviate undernutrition in vulnerable populations (notably infants, lactating mothers, and pregnant women). The project has already been piloted in several countries, including Burkina Faso, Ghana, and Malawi, among others. Some of their products had already been fortified by 2011 [71], namely, micronutrient powder (MNP) and lipid-based nutrient supplements (LNS); these are effective in reducing anemia and iron deficiency. Both are designed to be easily consumable by infants (thus advantageous over the pill forms commonly prepared as micronutrient pill supplements). However, an evaluation study [72] suggested that the micronutrients constituted in it may alone be insufficient to stimulate linear growth. Many studies (especially on LNS) applicable to different cultural settings are ongoing, despite challenges associated with adding micronutrients into the product.

Also introduced for better management of malnutrition are Ready-to-Use Therapeutic Foods (RUTF), which are high-energy lipid-based spreads that are designed to be used for the treatment of severe acute malnutrition (SAM) and in any cultural setting [62, 73]. F-75 and F-100 are two commonly available formulations from the World Health Organization (WHO) [74], which are used for the management of severe acute malnutrition. Their preparation process is elaborate [62], and the products are highly successful in terms of affordability and availability, in the management of malnutrition in various healthcare settings [73]. They are recommended by the World Health Organization and should gradually introduce until the child attains normal growth [75, 76]. Some have been successfully used in African countries, especially among children aged 5 years and below [67]. Like all other new formulations, the current and future challenges that RUTF may have should to be considered especially those concerning their safety, reliability, and affordability with short- and/or long-term use.

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