2 The Field Assessment of Nutrition

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CONTENTS

KEY POINTS

- Undernutrition contributes globally to more than 50% of deaths among children below the age of 5 yr.
- Nutritional assessment is the cornerstone of comprehensive child health care and should be implemented at all levels of care.
- Clinical, dietary, and anthropometric measurements are the main components of nutritional assessment.
- Different methods are available for assessing dietary intake, and each has its strengths and limitations. All, however, require the use of well-trained and experienced personnel.
- Growth monitoring and the use of clinical signs based on the World Health Organization's (WHO) Integrated Management of Childhood Illness strategy can identify children in need of nutrition intervention, especially at the primary care level.
- Underweight, wasting, and stunting based on the WHO Z-score cutoff values are recommended for screening individuals and populations. They are also useful for monitoring the effectiveness of nutrition interventions.
- Although limited quantitatively, body mass index and skinfold thickness measurements can be used to screen for obesity at both the individual and population level.

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- Deuterium dilution, dual energy X-ray absorptiometry, and bioelectrical impedance more accurately determine body composition than equations based on skinfold thickness, but their use is limited in resource-poor settings.
- Biochemical tests are used to assess the micronutrient status of individuals and/or populations. However, some indicators, such as ferritin, zinc, and retinol, are acute phase reactants; thus they may not reflect status in the presence of subclinical or clinical infections.

Introduction

Malnutrition in early childhood interacts synergistically with infectious disease resulting in increased morbidity, mortality, and impaired cognitive development *(1)*. Every year, 10.8 million under-5-yr-old children die in developing countries. Ninety percent of these deaths, which are mainly caused by neonatal disorders, diarrhea, pneumonia, malaria, and HIV/AIDS, occur in 42 countries. Undernutrition contributes to over 50% of childhood deaths, and the risk of mortality is directly associated with the degree of underweight *(2)*. Changes in weight-for-age are significantly associated with changes in child mortality independent of socioeconomic and other health-related changes. Child and under-5 mortality rates could be reduced by 30% and 13%, respectively, with a 5% improvement in weight-for-age by 2005 *(2)*. In both developing and developed countries the prevalence of obesity is increasing. This is significant because obesity leads to an increase in nutrition-related noncommunicable disease and ultimately contributes to high adult mortality rates *(3)*.

Assessing malnutrition—both under and overnutrition—is important at both the individual and population level for developing strategies to improve health. This chapter provides an overview of nutritional assessment and its practical application in children and adolescents.

Assessing Nutritional Status

Nutritional status can be determined clinically, from dietary data, and/or from anthropometric measurements. Indicators of body composition and nutritional biochemistry are also important, but their measurement is not always feasible. Age-related changes in dietary requirements, growth patterns, body composition, and disease epidemiology complicate the nutritional assessment of children.

Medical History (4,5)

A detailed medical history is obtained from the mother/caregiver for all children presenting at a health facility. This includes information about any underlying illness such as diarrhea, nausea and vomiting, intestinal parasites, malaria, cough, symptoms of HIV/AIDS, tuberculosis, or measles, as well as any previous illnesses or exposure to chronic illness such as tuberculosis. The child's immunization status is checked and special attention given to any reported changes in the child's weight and the direction of his or her growth curve on the Road to Health Card. It is important to ask about family circumstances including type of housing, access to water and sanitation, and the availability of cooking fuel as well as maternal age and education, family size, income, and emotional and social support.

Dietary Intake (4,5)

For children under 2 yr old, whether the child is exclusively breastfed or formula fed and whether the child is receiving complementary food is recorded. Where formula or complementary food are used, the type, amount, frequency of feeding, brand, and method of preparation is also noted. For children 2 yr and older, the type, quantity, and frequency of foods and liquids consumed daily are recorded. For all children, appetite, food aversions, and dietary restrictions, as well as the use of any drugs including vitamin and mineral supplements, are noted.

Dietary intake is recorded using a 24-h dietary recall, a food frequency questionnaire, a food record diary, or a dietary history. The strengths and limitations of these methods are shown in Table 1. Data collection requires input from a dietitian or nutritionist trained in the different methods. Irrespective of the method used, the mother/caregiver will provide data for infants and young children, but older children and adolescents must also report what they ate as food is often eaten outside the home.

In a 24-h recall the respondent recalls and provides a detailed description of all food and drink consumed, including cooking methods and brand names (where possible), on the previous day. Food quantities are measured using household measures or food models. Because of day-to-day variation in food intake, a single 24-h recall is not appropriate for assessing the usual food or nutrient intake of individuals. At the population level, it is also not appropriate for young children because there is too much intra- and interindividual variation.

The food frequency questionnaire asks about the frequency (daily, weekly, monthly, or yearly) of consumption of major foods. Quantitative data are not usually provided.

In the food record diary method the respondent records at the time of consumption all the foods and beverages eaten—using household measures or by weighing—over a specified period. The foods eaten are described in detail, as is their method of preparation and cooking.

Table 1
Strengths and Limitations of Dietary Assessment Methods

Method	Strengths	Limitations
24-hour recall	• Relatively easy to administer • Inexpensive • Provides detailed information on foods consumed • Low respondent burden • Can be used in clinical and epidemiological studies • Can be used to quantify nutrient intake • More objective than dietary history	• A single recall may not be representative of usual intake • Under or over reporting possible • Relies on memory and motivation of respondent • Omissions can result in low energy intake estimates • Data entry and analysis is time consuming
Food frequency questionnaire	• Can be self-administered if subjects are iterate • Moderate response burden • Inexpensive • Can be used in epidemiological studies • Can be used to assess associations between diet and disease	• May not represent seasonal foods • Portion sizes not determined • With single listings dietary intake data may be compromised • Cannot use to determine nutrient intake

Food record	• Not memory-dependent • Provides information about eating habits • More representative of actual intake • Reasonably valid up to 5 d	• Requires good cooperation • High response burden • Subject must be literate • Time consuming • Diet may alter with need to record • Analysis is expensive and labour intensive
Diet History	• Can detect seasonal changes	• Time consuming • Skilled interviewers needed • Difficult and expensive to code • Can overestimate intake • Need good cooperation • Not good for large surveys • Provides qualitative rather than quantitative data

Source: Adapted from refs. *4, 5*

The dietary history assesses the individual's dietary intake over a month or year. In addition to a 24-h recall on actual intake, respondents are asked about their general eating pattern, both at meal times and between meals. This includes information on the foods, their frequency of consumption, and usual portion sizes in household measures.

Food consumption data are converted into nutrient intake using food composition tables and reported as percentage of the recommended daily allowances.

Clinical Assessment

The clinical assessment of any child presenting at a health facility is based on the Integrated Management of Childhood Illness strategy. First, the child is checked for general danger signs such as an inability to drink or breastfeed, persistent vomiting, convulsions, lethargy, or loss of consciousness. The presence of any danger sign requires urgent assessment, specific management, and referral to the nearest hospital. After asking about the main problem(s) such as cough or difficulty breathing, diarrhea, fever, or an ear problem, the nutritional status of the child is determined *(6)*.

Physical Examination

Severe wasting over the shoulders, arms, ribs, buttocks, and thighs indicates marasmus, whereas edema over the dorsum of both feet is an early indicator of kwashiorkor (*see* Chapter 4). Other signs of kwashiorkor include hepatomegaly; changes in the hair, skin, and mucous membranes; apathy; and anemia (*see* Table 2) *(7–9)*. Children with undernutrition or severe undernutrition (marasmus and kwashiorkor) are at high risk of mortality *(10)*. All children must be examined for clinical signs and symptoms of vitamin A deficiency (*see* Table 2), fever or hypothermia, and underlying infection such as pneumonia, tuberculosis, and HIV/AIDS *(11)*.

An examination of the conjunctivae and palms for pallor or a finger-prick hemoglobin (Hb) test will identify anemia. Severe palmar pallor or a Hb below 70 g/L indicates severe anemia, while palmar pallor and a Hb below 110 g/L in children 6 mo to 5 yr, below 115 g/L in children 5–11 yr, below 120 g/L in children 12–13 yr and adolescent girls, and below130 g/L in boys 13+ yr indicates anemia *(12)*.

Children's thyroids are checked for visible signs of goiter that may indicate iodine deficiency.

Table 2
Clinical Features of Undernutrition and Micronutrient Deficiency

Parameter	Clinical features
Skin	• Pallor especially palms (anemia from iron or folate deficiency) • Ecchymoses (vitamin K deficiency) • Hypo or hyperpigmentation, desquamation, ulceration (zinc or protein deficiency) • Hyperpigmentation exposed areas (niacin deficiency) • Perifollicular hyperkeratosis (vitamin A deficiency)
Eye	• Night blindness, xerotic conjunctivae, xerotic cornea, Bitot's spots, keratomalacia, corneal scars (vitamin A deficiency) • Conjunctival pallor (anemia from iron or folate deficiency)
Hair	• Depigmentation, easy pluckability, sparsity (kwash-iorkor)
Nails	• Koilonychia (iron deficiency)
Mouth	• Cheilosis, glossitis, loss of papillae, magenta tongue (riboflavin deficiency) • Glossitis, scarlet tongue (niacin deficiency) • Bleeding gums (vitamin C deficiency)
Subcutaneous tissue	• Reduced subcutaneous tissue and fat (energy deficiency) • Odema (sodium and potassium disturbances, hypoal-buminemia)
Muscle bulk	• Muscle wasting, weakness (undernutrition)
Bones	• Craniotabes, prominent costochondral junctions, widening of metaphyses (wrists and ankle), frontal bossing, wide anterior fontanelle, rickety rosary, delayed dentition, bow legs (vitamin D deficiency) • Bony tenderness, pseudoparalysis (vitamin C deficiency) • Inadequate bone mass or osteoperosis (calcium)
Abdomen	• Hepatomegaly (kwashiorkor)
Central nervous	• Apathy (kwashiorkor, iron deficiency) system • Peripheral neuropathy (thiamin or pyridoxine deficiency)
Cardiac	• Cardiac failure or enlargement (thiamin deficiency)
Thyroid	• Goiter (iodine deficiency)

Source: Adapted from refs. *7–9*.

Table 3
Advantages and Limitations of Using Anthropometric Measurements

Advantages	Limitations
• Unskilled personnel can be easily trained • Reproducible • Reflects recent or longstanding nutritional changes	• Affected by non-nutritional factors • Does not indicate specific nutrient deficiencies

Anthropometry (4,5,13)

All children presenting at a health facility need to be weighed and their weight plotted on their weight-for-age chart or Road to Health Card. A child is categorised as having good growth (growth curve following the percentile curves), growth faltering or failure (growth curve flat or dropping below the percentile curves), underweight-for-age (weight 60–80% expected weight without edema), kwashiorkor (weight 60–80% expected weight with edema) or marasmus (weight below 60% expected weight without edema).

Anthropometric measures include physical measurements of weight, height, head circumference, mid upper arm circumference, and skin fold thickness that are compared to reference values. The first three assess growth while the latter two can be used to estimate body composition. The strengths and limitations of using these measurements are shown in Table 3. A single measurement generally indicates cumulative growth, while repeated measurements show whether growth is proceeding normally.

HEAD CIRCUMFERENCE

Head and brain growth is maximal during the first two years of life, after which growth is very slow. Head circumference is measured with the infant or child seated on the caregiver's lap. A nonstretchable measuring tape is positioned just above the eyebrows and over the occiput. Measurement is read to the nearest 0.1 cm.

LENGTH OR HEIGHT (STATURE)

Two people are always needed to take length or height measurements. Children below 2 yr of age, or less than 85 cm, are measured in the supine position using a measuring board with a fixed headboard and a moveable footboard that is perpendicular to the headboard. One person positions the child's head against the headboard and aligns the body centrally keeping shoulders and buttocks against the backboard. The head is positioned in the Frankfurt horizontal plane, which is a line joining the lowest point of the margin of the orbit and the tragion (the notch above the tragus) with the face positioned upwards. The other person straightens the legs and brings the footboard up to the heels. Children over 2 yr old, or more than 85 cm tall, are measured standing up using a portable anthropometer, a non-stretchable tape attached to a wall, or a stadiometer. The child stands with the heels together, knees straight, and heels, buttocks, and shoulders touching the vertical surface of the anthropometer, wall, or stadiometer with the head positioned in the Frankfurt plane and arms hanging loosely by the sides. Both length and height are recorded to the nearest 0.1 cm. Length measurements are 0.5–1.5 cm greater than height measurement. If length is measured in children over 2 yr old, or greater than 85 cm tall, it is recommended that that 1 cm be subtracted from the length measurement before comparing it with the reference.

Weight

Ideally, a spring, beam balance, or electronic scale is used to measure weight. Bathroom scales are not accurate and should be avoided. Scales must be calibrated regularly with a known set of weights and always zeroed before weighing the child. Children are weighed naked or with minimal clothing, and care must be taken to ensure the child is not touching any person or surrounding objects while being weighed. Weight is recorded to the nearest 0.1 kg, and plotted on the growth chart.

Mid-Upper-Arm Circumference (MUAC)

MUAC measurements reflect the amount of subcutaneous fat and muscle, and changes correlate positively with changes in weight. A decrease in MUAC indicates a reduction in one or both of these tissues. MUAC measurements are made using a flexible, nonstretchable tape. Measurement is done with the subject standing erect and the arms hanging by the sides. The midpoint of the upper arm is first located by flexing the right elbow to a 90° angle with the palm facing upward. Using a measuring tape, the observer identifies and marks the midpoint between the lateral tip of the acromion and the distal tip of the olecranon processes. With the arm extended and hanging by the side just away from the trunk with the palm towards the thigh, the tape measure is placed around the arm at the marked midpoint. The tape is pulled snug around the arm and the circumference is recorded to the nearest 0.1 cm.

Skinfold Thickness

Skinfold thickness measurements can provide an estimate of the amount of subcutaneous fat and total body fat. The commonly used skinfolds include triceps, biceps, subscapular, suprailiac, and midaxillary. Measurements from at least two sites are needed and it is recommended that a limb (for example, triceps) and body (for example, subscapular) skinfold measurement are used as these correlate best with measures of body fat. Lange or Holtain calipers are needed to measure skinfold thickness. To measure triceps skinfold thickness, the subject stands erect with the arms hanging by the side. The midpoint of the upper arm is first identified as for MUAC. A vertical fold of skin and subcutaneous tissue is then picked up between the thumb and index finger 1 cm proximal to the marked midarm level and the tip of the callipers applied perpendicular to the skinfold. The biceps skinfold is measured over the anterior aspect of the arm over the belly of the muscle opposite to the triceps skinfold site. The site for measuring the subscapular skinfold is below the inferior angle of the left scapula along a 45° diagonal to the horizontal plane. With the subject standing erect and the arms relaxed by the side, a pinch of skin and subcutaneous tissue is taken at a point 1 cm above and medial to the site. The suprailiac skinfold is measured above the suprailiac crest in the midaxillary line with the subject standing. The skinfold is picked up obliquely just posterior to the midaxillary line and parallel to the cleavage lines of the skin. The midaxillary skinfold is picked up horizontally in the midaxillary line at the level of the xiphoid process. Three readings are taken at each site and the mean used as the measure. Skinfold thickness are recorded to the nearest 0.5 mm using Lange callipers and 0.2 mm using Holtain callipers.

Use and Interpretation of Anthropometric Indices

The main anthropometric measurements and indices are listed in Table 4.

Head Circumference-for-Age *(4)*

Chronic undernutrition in early infancy or intrauterine growth retardation may affect brain development and result in a low head circumference. Head circumference-for-age can be used as an indicator of chronic undernutrition in children under 2 yr old. Microcephaly is a head circumference below the third percentile and may be due to a prenatal or perinatal cerebral insult. Macrocephaly is a head circumference above the 97th percentile and may be due to hydrocephalus.

Weight-for-Age, Weight-for-Height, Height-for-Age *(4,13)*

The weight or height of an individual is compared against a known reference of the same age or height. The most widely used reference is that of the US National Centre for Health Statistics (CDC/NCHS/WHO). Anthropometric indices are reported using three different systems namely Z-scores, percentiles, or percentage of the median.

The Z-score or standard deviation (SD) unit is the difference between the value for an individual and the median value of the reference population for the same age divided by the SD of the reference population

$$Z\text{-}score = \frac{(observed\ value) - (median\ of\ the\ reference\ population)}{SD\ of\ the\ reference\ population.}$$

The advantage of this index is that the curves are normally distributed and a fixed Z-score interval corresponds to a fixed weight or height difference for children of a given age. Additionally, summary statistics such as means and standard deviations can be calculated for a population.

Percentiles rank individuals according to a reference distribution and are useful in clinical settings because their interpretation is straightforward. They are not, however, useful for assessing the nutritional status of a population because they are not normally distributed and the same percentile interval may correspond to different changes in weight and height according to the part of the distribution concerned.

The percentage of the median is the ratio of an individual's measured value to the median value of the reference population for the same age or height for the specific sex, expressed as a percentage. The percentage of the median can be used to calculate population summary statistics. The main disadvantage is that a fixed point of the distribution may not be uniform across different ages.

Because of the limitations of percentiles and the percentage of the median, the WHO recommends that Z-scores be used; thus, the focus is on these indices.

- Stunting is defined as a height-for-age Z-score below –2 SD and indicates long-term undernutrition. Severe stunting is a Z-score below –3 SD.
- Underweight is defined as a weight-for-age Z-score below –2 SD and may reflect either recent or long-term undernutrition as it is dependent on both attained weight and height. Severe underweight is a Z-score below –3 SD.
- Wasting is defined as weight-for-height Z-score below –2 SD and reflects recent failure to gain weight or loss of weight. Severe underweight is a Z-score below –3 SD.

Although the CDC/NCHS/WHO growth reference is widely used and recommended, four technical issues limit its use *(13,15,16)*. First, the growth reference was developed from two different data sets. The longitudinal weights and lengths of formula fed children from the Fels Research Institute Longitudinal Study were used for children under 2 yr old, while data from three representative surveys that included standing heights were used for children over 2 yr old. Because length measurements are greater than those for height for a given child, a discrepancy exists before and after 2 yr of age. Also, the children in the Fel's study were taller than those in the three surveys. The use

Table 4
Anthropometric Measurements and Indicators Used in Nutritional Assessment

Measurement	Indicators and indices	Age groups	Usefulness	Disadvantages	Explanation
Weight	Underweight: Wt/age Z-score <–2 SD	All	• Basic measure of nutrition status • Only when related to age or height • Trends over time better than a single measure • Used for growth monitoring	• Need accurate scales and age • Related to height and weight-for-height	• Underweight reflects acute and chronic undernutrition
Height	Stunting: Ht/age Z-score <–2 SD	All	• Related to long-term nutritional status • Serial measures more useful than a single measure	• Influenced by non-nutrition factors, for example, genetic and hormonal factors	• Stunting reflects long-term changes in nutritional status
Weight-for-height (wt/ht)	Wasting: Wt/ht Z-score <–2 SD	Girls ≤137 cm Boys ≤145 cm	• Age independent • Index of body proportion • Can be used in epidemiological surveys	• Not easy to calculate by hand	• Wasting reflects acute under-nutrition

Head circumference	Microcephaly: <3rd percentile Macrocephaly: >97th percentile	0–2 years	• Simple to measure	• Affected by non-nutrition factors • Not useful for assessing nutrition status	• May reflect intrauterine growth restriction and/or early childhood undernutrition
Mid upper arm circumference-for-age	Moderate wasting: Z-score <–2 SD Severe wasting: Z score <–3 SD	All	• Simple • Can use in rapid surveys	• No limits for over-nutrition • No standards for adults • Small errors have big implications	• Proxy for weight-for-height
Body mass index (BMI)	Thinness <5th percentile Overweight ≥85th percentile Obesity ≥85th percentile BMI and ≥90th percentile skinfold thickness	Older children Adolescents Adults	• Requires simple measurements • Can be used in epidemiological surveys	• Cannot use in younger children because varies with age • Does not differentiate fat from lean body mass • Not easy to calculate by hand	• Indirect measure of body composition

Source: Adapted from refs. *7, 14*.

of this reference standard can underestimate height status in children under 24 mo old and overestimate that in children over 24 mo old. Second, in population-based studies the 24-mo disjunction can result in variations in the prevalence of low weight-for-age when the nutritional status of children with a range of ages is assessed. Third, the weight-for-age curves are skewed toward the high end, which can result in misclassifying overweight children as normally nourished children. Fourth, the growth pattern of infants living under optimal conditions and fed according to the WHO recommendations differs from that of the CDC/NCHS/WHO reference population.

The limitations of the CDC/NCHS/WHO growth reference can lead to misinterpretation of growth patterns and result in the too early introduction of complementary food to infants who should be exclusively breastfed. This can adversely affect the health and nutritional status of these infants especially in poor communities. An international growth reference based on a representative, geographically diverse population of healthy children from birth to adolescence, who have no constraints on their growth is currently being developed *(17)*.

MUAC *(4,18)*

MUAC increases by about 2 cm between 6 and 59 mo of age. There are also sex specific differences for children below 24 mo of age. A combined MUAC-for-age reference using the US National Health and Examination Surveys has been developed, which can be used in determining the MUAC Z-scores for age. A MUAC Z-score below –2 SD can be used as a proxy for low weight-for-height (wasting) while a Z-score below –3 SD reflects severe wasting.

Body Mass Index (BMI) *(4,8,13)*

BMI is an indirect measure of body composition and is calculated by dividing weight in kg by height in m^2. Because it is correlated with both lean mass and fat mass, BMI does not distinguish between the two. Cutoff values are available for children in determining overweight and obesity and these are discussed in more detail below.

Application of Anthropometry

Newborn Infants *(13)*

Intrauterine growth restriction (IUGR) is not easy to measure and birth weight is often used as a proxy. However, birth weight is affected by intrauterine growth and gestation duration. WHO uses weight-for-gestational age at birth to categorize newborn infants as small-for-gestational age (SGA), appropriate-for-gestational age (AGA), or large-for-gestational age (LGA). Using an appropriate sex-specific international reference, SGA is defined as a birth weight below the 10th percentile, AGA a birth weight between the 10th and 90th percentiles, and LGA a birth weight above the 90th percentile.

SGA is not necessarily the same as IUGR because some SGA infants fall in the lower tail of the normal fetal growth distribution curve. Classification of an infant as IUGR should be based on a specific cutoff for SGA. Generally, the greater the prevalence of SGA the more likely this is as result of IUGR. For population-based studies, low birth weight (LBW) (below 2500 g), which can be measured with good precision and validity, is used as a proxy for SGA.

The criteria defining newborn nutrition as being of public health significance and warranting intervention are a SGA rate greater than 20%, LBW rate above 15%, and a very low LBW rate above 2%.

Fetal growth restriction can be further classified as symmetric or stunted, in which all body dimensions are proportionally small, or asymmetric or wasted, in which the fetus has a low ponderal index or BMI owing to a lack of fat and sometimes lean tissue. Symmetric growth restriction may reflect undernutrition throughout pregnancy while asymmetric growth restriction results from inadequate nutrition late in pregnancy when fat deposition is most rapid. Disproportionate IUGR infants tend to be more severely growth retarded and at greater risk of mortality.

Infants and Children *(13,19)*

Anthropometry is used for both individual and population-based nutritional screening and for program monitoring and evaluation.

The use of anthropometry to screen and monitor the nutritional status of individual infants and children is shown in Table 5. Primary health care or community-based growth monitoring and promotion (GMP) programs track changes in a child's physical development, by regular weighing and sometimes measurement of length, to identify infants and children in need of health and nutrition interventions. The essential components in a GMP program include taking preventive action before undernutrition occurs; effective communication with the mother/caregiver to change behavior; and taking cognizance of the health, nutrition, environmental and social factors that influence each child's growth. GMP is a component of primary health care and is linked to health interventions such as breastfeeding promotion and support, timing and selection of complementary feeding, identification of underlying disease such as tuberculosis and HIV/AIDS, and treatment of disease such as diarrhea and respiratory tract infections. Adequate weight gain is the main indicator for effective GMP but, where possible, attained weight-for-age, height-for-age, and weight-for-height should be assessed.

Table 5
The Use of Anthropometry in Screening and Monitoring Responses to Interventions in Individual Infants and Children

	Target group and setting	Recommended measurements	Indices for screening	Cut-offs	Indices for monitoring response to interventions	Criteria
Infants and children with poor growth who need support through: • Breastfeeding • Counseling • Prevention and treatment of disease, e.g., diarrhea	Children under 5 yr attending primary health care centers for growth monitoring	• Weight • Age • Gender • If possible, height /length every 3 mo	Deviation from weight-for-age curve Attained: • Wt/age • Ht/age • Wt/ht	• Direction of curve • Z-scores <–2 SD • No growth >2 visits • <3rd centile on growth chart	Wt/age curve Attained: • Wt/age • Ht/age • Wt/ht	• Direction of curve • Positive Z-score trend
Selection of infants and children for supplementary feeding	Children <5 years attending growth monitoring	• Weight • Height/length • MUAC • Age • Gender	• Wt/ht • MUAC/age	• <–2 SD wt/ht or • MUAC/age	Wt/age curve Attained: • Wt/age • Wt/ht	• Direction of curve • Positive Z-score trend
Selection of infants and children for therapeutic feeding	• Attendees at nutrition rehabilitation centers	• Clinical signs of severe under-nutrition	• Wt/ht • MUAC/age • Clinical signs of severe	• Clinical signs • <–3 SD wt/ht or • MUAC/age	Wt/age curve Attained: • Wt/age • Wt/ht	Z-score >–2SD wt/ht

	or hospitals • Children in refugee camps or emergency settings	• Weight • Height/length • MUAC • Age	under-nutrition		• Clinical signs	
Infants and children with organic disease or failure to thrive	Children attending: • Paediatric clinics • Hospitals	• Weight • Height/length • Age • Gender	Deviation of curves of: • Wt/age • Ht/age Change in: • Wt/age • Ht/age • Wt/ht	• Direction of curve • Z-scores <–2 SD • No growth >2 visits	• Wt/age • Ht/age Change in: • Wt/age • Ht/age • Wt/ht	• Satisfactory growth pattern
Overweight infants and children	Children attending: • Special clinics • Hospitals • Schools	• Weight • Height/length • Skinfold • Age • Gender	• Wt/ht • Skinfold	• Wt/ht >2+ Z-scores	• Wt/ht • Skinfold measures	• Reduction wt/ht Z-score

Source: Adapted from ref. *13*.

Weight-for-height and MUAC-for-age are useful indicators for screening children for enrollment into a supplementary program as these indices predict benefits from the intervention. The identification of severely undernourished children for therapeutic feeding is based on indices of severe wasting, (weight-for-height below –3 Z-scores), clinical signs of severe undernutrition, or low MUAC-for-age. Weight-for-age, weight-for-height, and clinical signs of severe undernutrition can also be used to monitor the response to supplementary feeding.

When a child fails-to-thrive, because of organic reasons, both the screening for and response to the intervention is based on weight and height indicators as well as serial measurements of growth. Weight-for-height can also be used to screen for overweight, using a cutoff value of +2 Z-scores and monitoring the reduction in weight-for-height or weight-for-age.

In assessing the prevalence of undernutrition in communities, and the response to interventions, a representative sample must be selected to enable comparisons to be made between populations. The nature of the intervention determines which indicators to use, as shown in Table 6. For example, height-for-age reflects cumulative growth, long-term nutrition, socioeconomic status, and overall health and development of communities and can be used to measure the response to an intervention. The WHO has proposed prevalence ranges for wasting, underweight, and stunting that define the extent to which undernutrition is a public health problem (*see* Table 7).

Adolescents *(13,20)*

The nutritional status of an individual or a population of adolescents can be assessed using height-for-age based on the NCHS/WHO reference, BMI-for-age, and subscapular or triceps skinfold thickness (*see* Table 8). For BMI, the reference data published by Must et al. *(20)* are recommended because the percentiles have been smoothed mathematically across age groups. Maturational status with age-specific means and medians adjusted for rates of maturation in relation to the reference population need to be factored in when assessing growth of adolescents *(13)*.

Body Composition (21–25)

Body composition is defined as the ratio of fat to fat-free mass and is usually expressed as the percentage of body fat. Measuring body composition in children is important for quantifying the prevalence of childhood obesity, determining fluid and energy requirements (linked to fat-free mass) in sick children requiring hospitalization, and to assess and treat growth disorders.

Two models have been proposed for measuring body composition. The two-component model, in which the body is divided into fat mass (adipose tissue)

Table 6
The Use of Anthropometry in Screening
and Monitoring Responses to Interventions in Populations of Infants and Children

	Target group and setting	Recommended measurements	Indices for screening	Cut-offs	Indices for monitoring response to interventions	Criteria
Infants and children in need of targeted interventions, e.g., breastfeeding support, supplementation of mothers, etc.	Nutrition surveys of representative sample of children under 5 yr in need of intervention	• Weight • Height/length • Age • Gender • One measurement	• Wt/age • Ht/age • Wt/ht	• Prevalence <–2 Z-scores • Difference in mean Z-scores	• Wt/age • Ht/age • Wt/ht	Significant difference in growth velocity, e.g., between intervention and control groups
Determining the severity of a disaster or emergency and the need for food aid	Rapid assessment surveys	• Weight • Height • MUAC • Clinical signs of severe undernutrition	• Wt/ht • MUAC/age (children 1–5 yr) • Clinical signs of severe undernutrition	• Prevalence <–2 Z-scores • Difference in mean Z-scores	• Wt/ht • Clinical signs of severe undernutrition	Reduction in prevalence of wasting using cutoffs for wt/ht and MUAC
Areas for targeting interventions in reducing food and fat consumption	Representative surveys	• Weight • Height/length • Height/length • Age • Gender • One measurement	• Wt/ht	• Prevalence >2+ Z-scores	• Wt/ht	Reduction in prevalence of wt/ht Z-score >+2 SD

Source: Adapted from ref. *13*.

Table 7
Severity Index in Children Under 5 yr Based
on Indices for Wasting, Stunting and Underweight, and Mean wt/ht Z-Score

	Prevalence (% children below –2 SD Z-scores)		
Prevalence	Stunting	Underweight	Wasting
Low/Acceptable	<20	<10	<5
Medium/Poor	20–29	10–19	5–9
High/Serious	30–39	20–29	10–14
Very high/Critical	≥40	≥30	≥5
			Mean wt/ht Z-score
Acceptable	—	—	–0.40
Poor	—	—	–0.40 to –0.69
Serious	—	—	–0.70 to –0.99
Critical	—	—	≤–1.00

Source: Ref. *13*.

Table 8
Recommended Cutoff Values for Anthropometric Indices in Adolescents

Indicator	Anthropometric variable	Cut-off value
Stunting	Height-for-age	<3rd percentile or <–2 Z-score
Thinness or low BMI-for-age	BMI-for-age	<5th percentile
At risk of overweight	BMI-for-age	≥85th percentile
Obese	BMI-for-age	≥85th percentile
	Triceps skinfold-for-age	≥90th percentile
	Subscapular skinfold-for-age	≥90th percentile

Source: Ref. *13*.

and fat-free mass (muscle, bone, water, and tissues devoid of fat/lipid), and the four-component model, in which the body comprises water, protein, mineral, and fat. The different methods for assessing body composition and their advantages and limitations are outlined in Table 9. Skinfold thickness, BMI and densitometry, bioelectrical impedance, and total body electrical conductivity measure body composition based on the two-component model. Neutron activation analysis, isotope dilution, and dual-energy X-ray absorptiometry measure body composition based on the four-component model, but can also be used to measure fat mass and fat-free mass.

Skinfold thickness measurements can be used to quantify the percent body fat using equations. However, because of inaccuracies in the equations, this method may underestimate fatness in children.

Densitometry measures the body density through hydrostatic or underwater weighing. It is based on Archimedes principle whereby the volume of a submerged object is equal to the volume of the water displaced. An individual's density is determined from the mass and volume measurements, after which it is used to calculate the percent body fat and fat free mass (FFM). Because the densities of fat and fat-free mass are assumed constant, the proportion of these compartments can be calculated using a known value for body density. This technique, however, has limited value in children because it is not always safe to submerge children in water.

Total body water (TBW) can be measured indirectly by dilution using a tracer substance given either orally or parentally that disperses uniformly throughout the water space. Isotopes of hydrogen such as deuterium or tritium and oxygen (^{18}O) are used. Tritium cannot be used in children and women of reproductive age because of its radioactivity; whereas deuterium and ^{18}O are stable and are ideal. The concentration of the tracer in a sample of the subject's blood, urine, or saliva is analyzed and TBW is measured using a formula. Disease states can alter the total body water resulting in inaccuracies in the estimation of the fat-free mass.

More than 90% of potassium in the body is in the fat-free mass; thus, fat-free mass can be estimated from the total amount of body potassium obtained from a whole body counter. This, however, assumes that the fat-free mass contains a constant amount of potassium.

Neutron activation analysis can estimate the body's content of sodium, chloride, phosphorous, carbon, and nitrogen. A beam of neutrons is delivered to the subject, which interacts with the specific elements and emits gamma radiation that is picked up by detectors. Measurements of total body nitrogen and carbon can be used to determine the total amount of body protein and fat, respectively. Bone mineral content can be determined through the measurement of total body calcium.

Fat-free mass has a better electrical conductivity than fat because of the higher concentration of electrolytes, which are capable of conducting electricity. In bioelectrical impedance analysis (BIA) an electronic instrument generates an alternating current, which is passed through the body and a measurement of the resistance (impedance) to the current is used to calculate TBW, fat-free mass, and percent body fat. BIA equations were previously based on the two-component model. Recently, using a multicomponent model, sex-specific and race-combined BIA equations using pooled data from white and black subjects between 12 and 94 yr old from different centers were developed. The equations were validated and cross-validated for TBW and FFM and found to have good precision and accuracy. The equations were more valid for white people than black people, where they tended to under predict TBW and FFM. The authors advise caution when applying the equations to children between

Table 9
Strengths and Limitations of Body Composition Methods

Method	Strengths	Limitations
Skinfold thickness	• Inexpensive • Quick • Measures correlate well with underwater weighing	• Interindividual variation in skinfold compressibility • Variation in the contribution of skin to skinfold thickness measurement • Variation in subcutaneous skinfold thickness between sites • Subcutaneous fat may not correlate with internal fat • Skilled measurers required
Densitometry	• Standard procedure for determining body density and percent fat	• Cannot be used for large studies • Dependent on subject cooperation • Requires special equipment • Requires experience • Assumes constant density of fat-free mass
Isotope dilution	• Isotopes of deuterium and oxygen are stable and safe to use	• Cost of the equipment • Time-consuming • Radioactivity of tritium limits its use in children and women of reproductive age • Water content in fat-free tissue can vary especially in fat subjects

Total body potassium	• Good precision	• Expensive • Overestimation of fat content in the obese
Neutron activation analysis	• Good precision • Noninvasive • Not based on fixed ratios of body compartments	• Exposure to ionizing radiation • Expensive • Requires skilled operators • Units not mobile
Bioelectrical impedance	• Good precision for calculations of total body water • Safe and non-invasive • Portable • Quick	• Assumes normal hydration • Expensive
Dual-energy X-ray absorptiometry	• Low radiation dose • Quick (20–20 min) • Requires little cooperation • Results correlate well with other methods	• Affected by hydration status • Results affected by part being scanned

Source: Refs. *5*, *8*, *22*.

12 yr and maturity as maturational development could influence the results. Despite this, the equations have been recommended for use in large epidemiological studies that describe normal levels of body composition.

Dual-energy X-ray absorptiometry (DEXA) is useful for measuring fat and lean tissue. Estimates of percent body fat using DEXA correlate well with those of underwater weighing.

The two-component model relies on the assumption that properties such as hydration and density of FFM are constant. However, FFM can vary between individuals of the same age and sex, with age and in disease states involving overhydration, underhydration, muscle wasting, mineral loss, or edema. All of these can reduce the validity of the measurements. Inter individual variations can be overcome by using appropriate reference values or techniques such as isotope dilution, which provides a more accurate assessment of body composition based on the two-component model. The use of multicomponent models of body composition, which quantify the sources of variability, may be more appropriate in disease states than two-component models.

Another shortcoming in reporting body composition relates to fat mass (FM) expressed as a percentage of body weight when no adjustment is made for FFM based on size. Percent body fat is dependent on both FM and FFM. Individuals who differ in percent fat may do so because they have differences in FM, but identical FFM or because they have the same FM but differences in FFM. Similarly, disease states may modify FM and FFM and these changes will not be detected in the individual using percent body fat. It is recommended that FM and FFM are normalized for height dividing by height squared and that age- and sex-specific reference data are developed. Body composition can be used to evaluate the prevalence of obesity and to monitor interventions.

Nutritional Biochemistry (4,5,26,27)

Laboratory investigations are not routinely used to assess nutritional status because of the absence of a single laboratory test or a group of tests or indicators that can be used reliably to measure nutritional status. Moreover, the equipment required for most of laboratory tests is not readily available in situations where they are most needed and where undernutrition is common. Nevertheless, biochemical markers are important in some situations and should be regarded as an adjuvant tool to clinical assessment, anthropometric measurement, and dietary intake assessment that are currently regarded as the best methods for assessing overall nutritional status. Table 10 summarises the usefulness of some laboratory tests that can be used in nutritional assessment.

Nutritional biochemistry can be conveniently and arbitrarily divided into static and functional tests. Static tests are a direct measurement of a nutrient or related metabolite in the blood or other body fluids. However, blood levels

Table 10
Usefulness of Selected Laboratory Tests for the Assessment of Nutritional Status

Nutrient	Test	Usefulness	Availability*	Comments
Protein	Serum protein and albumin	Poor	Available	Reduced in liver and renal disease
	Transferrin and transthyretin	Good	Limited	Reduced in infections
	Nitrogen balance	Good	Research tool	
Vitamin A	Serum retinol	Poor	Limited	Reduced with acute phase response
	Retinol binding protein	Poor	Limited	
Vitamin D	Plasma calcium and phosphate	Good	Available	May be first sign of deficiency
	25 OH Vitamin D	Good	Limited	
	1,25 Di OH Vitamin D	Good	Limited	
Folate	Serum folate	Good	Available	Reflects recent uptake
	Red cell folate	Good	Available	Reflects whole body status
Iron	Serum ferritin	Good	Available	Reduced with acute phase response
	Bone marrow iron	Good	Limited	
	Serum iron and total iron binding capacity	Poor	Available	Reduced with acute phase response
Zinc	Plasma zinc	Good	Available	Increased with acute infections
	Plasma alkaline phosphatase	Poor	Available	
Copper	Plasma copper	Good	Limited	
Iodine	Thyroid function tests	Good	Limited	

Adapted from refs. *26* and *27*.
*Most of these tests are not available in primary care situations and will generally be available in regional hospitals. However, in many developing countries they may only be available in specialist centres.

frequently do not reflect true tissue stores. For example, albumin and calcium declines late in the course of protein deficiency or rickets, respectively. Other factors also influence test results including the presence of fever owing to acute and chronic infections, concomitant medical conditions, general nutritional status, interaction with drugs, sample collection procedures, and the assay used. Examples of static tests include measurement of serum albumin, calcium, potassium, vitamin A, ferritin.

Functional or indirect tests measure a specific physiological or biochemical reaction. These tests are less affected by recent changes in food and fluid intake. However, they are usually influenced by a number of nutrient abnormalities. Functional tests include dark adaptation to measure vitamin A status and immunological tests.

In general, nutritional biochemistry is used at the individual level: to assess macro and micronutrient status; as a prognostic indicator for morbidity and mortality; to identify specific metabolic abnormalities frequently associated with systemic disorders; and to monitor specific therapeutic interventions. At a population level, nutritional biochemistry is used to screen for micronutrient deficiencies such as vitamin A and iron and to monitor specific population-based interventions.

Whereas laboratory tests for nutritional biochemistry may not be practical in most situations, other laboratory tests are extremely useful for excluding a chronic infection such as tuberculosis, HIV, or parasitic infestation in children who are failing to thrive. These tests are also useful as a diagnostic aid to exclude hypoglycemia in a sick infant or child who presents with convulsions (finger-prick dextrostix); identify children with severe anemia (finger-prick hemoglobin); and exclude urinary tract infections in febrile undernourished children (dipsticks).

Conclusion

Nutritional assessment is the cornerstone in comprehensive child health care. The presence of general danger signs or signs of severe undernutrition (severe wasting and bipedal edema) and severe anemia (severe palmar pallor) can be used at the primary care level to determine whether children need referral for hospitalization. At a population level, clinical signs of undernutrition and micronutrient deficiencies need to be supported by anthropometric and biochemical data when deciding about nutrition interventions.

The most useful anthropometric indices are weight-for-age, height-for-age, and weight-for-height that indicate underweight, stunting, and wasting, respectively. Fixed cutoff values exist for each indicator and they can be used for screening as well as monitoring the effect of interventions. WHO recommends the three indices are presented as Z-scores in epidemiological surveys because this allows summary statistics to be computed. MUAC too reflects acute undernutrition and is particularly useful in rapid surveys. Age- and sex-specific graphs or tables rather than fixed cutoff values should be used to assess undernutrition using MUAC.

The CDC/NCHS/WHO growth reference is widely used although it has limitations. A new growth reference is being developed by WHO that will reflect the growth of children from diverse geographical and cultural backgrounds fed according to the WHO feeding recommendations.

BMI-for-age and triceps and subscapular skinfold thickness percentiles can be used to screen for obesity, although there are limitations in measuring fat mass in quantitative terms. Measurements of body composition using deuterium dilution and DEXA are more accurate. The accuracy and precision of techniques such as bioelectrical impedance has been improved using revised equations, and have been recommended for epidemiological studies. However, cost needs to be considered before such techniques can be recommended widely for epidemiological use.

Nutritional biochemistry can be used at the individual and population level to determine nutrition and micronutrient deficiencies. Static tests that measure concentrations of serum retinol, zinc, calcium, and albumin, for example, do not necessarily reflect tissue stores because they are acute phase reactants and respond to underlying infection. There are, however, other tests that have practical importance such as finger-prick dextrostix or hemoglobin. Ideally, biochemical investigations should serve as an adjuvant in the clinical and anthropometric assessment of children and adolescents.

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