Special Report

Defining Pediatric Malnutrition: A Paradigm Shift Toward Etiology-Related Definitions

Journal of Parenteral and Enteral Nutrition
Volume 37 Number 4
July 2013 460-481

DOI: 10.1177/0148607113479972
jpen.sagepub.com
hosted at
online.sagepub.com

Nilesh M. Mehta, MD[1]; Mark R. Corkins, MD, CNSC, SPR, FAAP[2]; Beth Lyman, MSN, RN[3]; Ainsley Malone, MS, RD, CNSC[4]; Praveen S. Goday, MBBS, CNSC[5]; Liesje (Nieman) Carney, RD, CSP, LDN[6]; Jessica L. Monczka, RD, CNSD[7]; Steven W. Plogsted, PharmD, RPh, BCNSP, CNSC[8]; W. Frederick Schwenk, MD, FASPEN[9]; and the American Society for Parenteral and Enteral Nutrition (A.S.P.E.N.) Board of Directors

Abstract

Lack of a uniform definition is responsible for underrecognition of the prevalence of malnutrition and its impact on outcomes in children. A pediatric malnutrition definitions workgroup reviewed existing pediatric age group English-language literature from 1955 to 2011, for relevant references related to 5 domains of the definition of *malnutrition* that were *a priori* identified: anthropometric parameters, growth, chronicity of malnutrition, etiology and pathogenesis, and developmental/ functional outcomes. Based on available evidence and an iterative process to arrive at multidisciplinary consensus in the group, these domains were included in the overall construct of a new definition. Pediatric malnutrition (undernutrition) is defined as an imbalance between nutrient requirements and intake that results in cumulative deficits of energy, protein, or micronutrients that may negatively affect growth, development, and other relevant outcomes. A summary of the literature is presented and a new classification scheme is proposed that incorporates chronicity, etiology, mechanisms of nutrient imbalance, severity of malnutrition, and its impact on outcomes. Based on its etiology, malnutrition is either *illness related* (secondary to 1 or more diseases/injury) or *non–illness related*, (caused by environmental/behavioral factors), or both. Future research must focus on the relationship between inflammation and illness-related malnutrition. We anticipate that the definition of malnutrition will continue to evolve with improved understanding of the processes that lead to and complicate the treatment of this condition. A uniform definition should permit future research to focus on the impact of pediatric malnutrition on functional outcomes and help solidify the scientific basis for evidence-based nutrition practices. (*JPEN J Parenter Enteral Nutr*. 2013;37:460-481)

Keywords

pediatrics; outcomes research/quality; nutrition assessment; growth; malnutrition; undernutrition

Evaluation of nutrition status and provision of adequate nutrition are crucial components in the overall management of children during illness because malnutrition is prevalent and affects normal growth, development, other clinical outcomes, and resource utilization.[1] Large-scale international studies have attributed a majority of all childhood deaths to undernutrition, with high relative risks of mortality for severe malnutrition.[2,3] In the developed world, malnutrition is predominantly related to disease, chronic conditions, trauma, burns, or surgery (henceforth referred to as illness-related malnutrition in this article). Illness-related malnutrition in children may be attributed to nutrient loss, increased energy expenditure, decreased nutrient intake, or altered nutrient utilization. These factors are seen frequently in relation to acute illnesses such as trauma, burns, and infections, as well as chronic diseases such as cystic fibrosis, chronic kidney disease, malignancies, congenital heart disease (CHD), gastrointestinal (GI) diseases, and neuromuscular diseases. In addition to the anthropometric changes in acute malnutrition, chronic malnutrition may be characterized by stunting (decreased height velocity).

Although several studies have reported a prevalence of illness-related malnutrition of 6%–51% in hospitalized children, this condition is probably underrecognized.[4-6] Lack of uniform definitions, heterogeneous nutrition screening practices, and failure to prioritize nutrition as part of patient care are some of the factors responsible for underrecognition of the prevalence of malnutrition and its impact on clinical outcomes. To date, a uniform definition of malnutrition in children has remained elusive. Current terminologies such as protein-energy malnutrition, marasmus, and kwashiorkor describe the effects of malnutrition but do not account for the variety of etiologies and dynamic interactions that are relevant to nutrition depletion in children. A better definition of malnutrition is essential to reach the following goals: (a) early identification of those at risk of malnutrition, (b) comparison of malnutrition prevalence between studies and centers, (c) development of uniform screening tools, (d) development of thresholds for intervention, (e) collection of meaningful nutrition data, and (f) evidence-based analysis of the impact of malnutrition and its treatment on patient outcomes.[7] To address this issue, an interdisciplinary American Society for

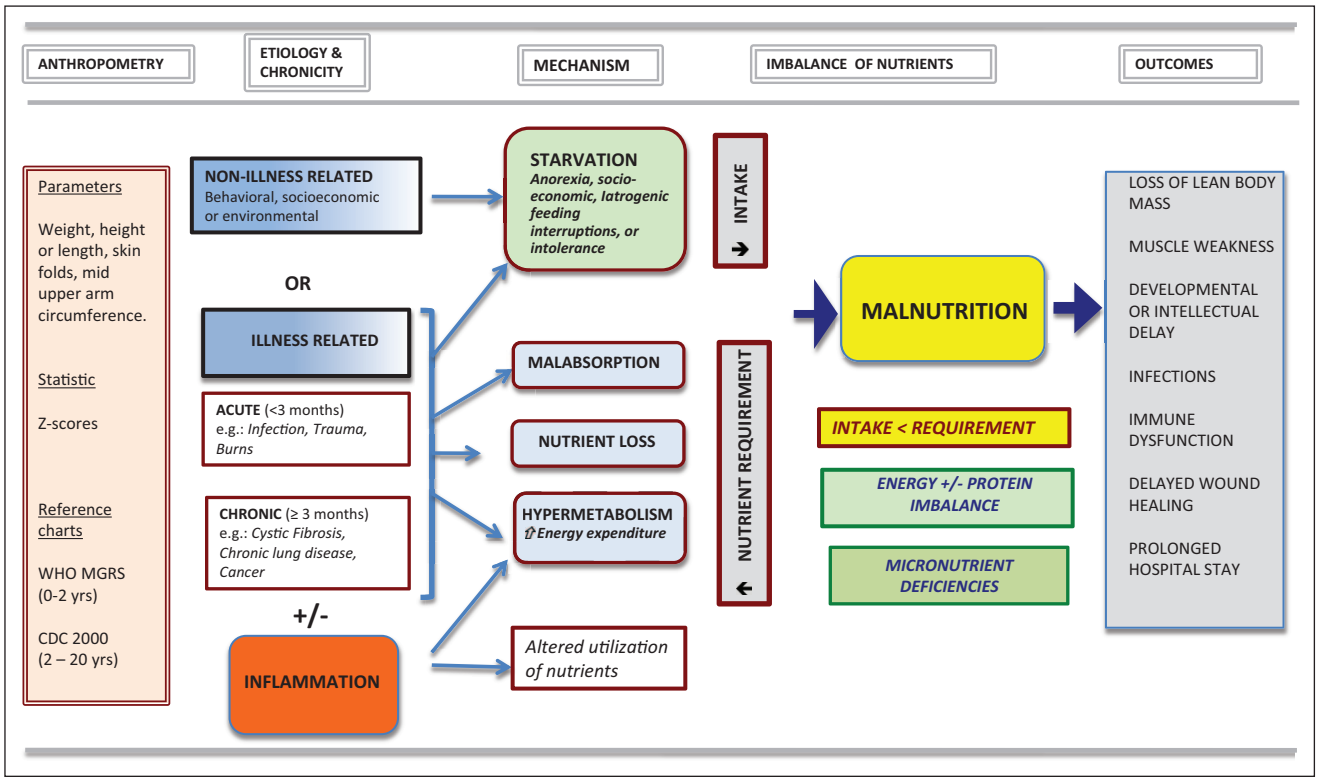

Figure 1. Defining malnutrition in hospitalized children: Key concepts. CDC, Centers for Disease Control and Prevention; MGRS, Multicenter Growth Reference Study; WHO, World Health Organization.

Parenteral and Enteral Nutrition (A.S.P.E.N.) working group of physicians, nurses, dietitians, and pharmacists was assigned the task of developing a uniform and comprehensive definition of malnutrition based on available evidence and multidisciplinary consensus. The working group reviewed the existing literature and developed a consensus on the important elements that should be included in a definition of pediatric malnutrition. This document describes the result of this multidisciplinary effort, including the rationale and proposal for a novel definition of pediatric malnutrition. Malnutrition includes both undernutrition and obesity. For the purpose of this document, only undernutrition will be discussed. The definition will not address malnutrition in the developing world or neonates (younger than 1 month old). Although a majority of evidence is expected to represent hospitalized children, the definition will address children in all settings.

From [1]Boston Children's Hospital, Boston, Massachusetts; [2]University of Tennessee Health Sciences Center, Memphis, Tennessee; [3]Children's Mercy Hospital, Kansas City, Missouri; [4]Mt Carmel West Hospital, Columbus, Ohio; [5]Medical College of Wisconsin, Milwaukee, Wisconsin; [6]The Children's Hospital of Philadelphia, Philadelphia, Pennsylvania; [7]Arnold Palmer Hospital for Children, Orlando, Florida; [8]Nationwide Children's Hospital, Columbus, Ohio; [9]Mayo Clinic, Rochester, Minnesota

Financial disclosure: Dr Mark Corkins is a consultant for Nestlé for their research studies and has served on their speakers bureau.

Endorsement: This document was endorsed by the American Academy of Pediatrics.

This article originally appeared online on March 25, 2013.

Corresponding Author:
Nilesh M. Mehta, MD, Associate Medical Director, Critical Care Medicine, Department of Anesthesiology, Pain and Perioperative Medicine, Boston Children's Hospital, MSICU Office, Bader 634 Children's Hospital, 300 Longwood Ave, Boston, MA 2115, USA.
Email: Nilesh.Mehta@childrens.harvard.edu.

Table 1. Practical Scheme for Pediatric Malnutrition Definition.

Chronicity	Suggested Criteria for Degree of Malnutrition (Anthropometry in Relation to Reference Curves)[a]	Etiology of Energy, Protein, and/or Micronutrient Imbalance	Inflammatory State (CRP, Cytokines)	Pathogenetic Mechanism (Resulting in Nutrient Intake < Requirement)	Outcomes Affected
Acute (<3 months' duration)	Mild malnutrition or at risk of malnutrition (*z* score <–1)	Illness related Specify disease(s)	Present Usually severe or moderate in acute illness and mild in chronic illness	Starvation (decreased nutrient intake) This may be disease-related food deprivation or behavioral/social (not disease related)	Muscle weakness Include muscle loss. Lean body mass depletion
Chronic (3 months or longer)	Moderate (*z* score between −2 and −3)	Not illness related; behavioral, socioeconomic	Absent Usually in malnutrition that is not related to illness but secondary to starvation from decreased intake/ delivery	Hypermetabolism (increased energy requirement)	Cognitive/ developmental delay/deficit
	Severe (*z* score <–3)			Uncompensated nutrient losses (malabsorption) Inability to use/ assimilate nutrients	Immune dysfunction Others: delayed wound healing, infections, ventilator dependence, longer hospital/ ICU stay, etc

CDC, Centers for Disease Control and Prevention; CRP, C-reactive protein; ICU, intensive care unit; WHO, World Health Organization.
[a]WHO for <2 y; CDC for 2–20 y. The specifics of anthropometric variables and thresholds for classifying the degree of malnutrition will be discussed in a separate document.

Executive Summary

A novel and comprehensive definition of pediatric malnutrition is proposed. A multidisciplinary working group identified 5 key domains relevant to the definition of pediatric malnutrition (see Figure 1). After a systematic review of the literature along these domains, the evidence was presented and synthesized to generate recommendations for a uniform definition. The process was completed by consensus for each domain, using an iterative process. The new classification scheme incorporates the chronicity, etiology, and severity of malnutrition (see Table 1 and Table 2). This scheme also accounts for the mechanism by which nutrient imbalance results in malnutrition, association with inflammation, and its impact on growth, development, and functional outcomes. A simultaneous effort to develop specific diagnostic criteria for identifying and classifying the severity of malnutrition based on anthropometric parameters is currently under way and will be published in the future.

In summary, pediatric malnutrition (undernutrition) is defined as an imbalance between nutrient requirement and intake, resulting in cumulative deficits of energy, protein, or micronutrients that may negatively affect growth, development, and other relevant outcomes. Based on its etiology, malnutrition is either (1) illness related (1 or more diseases/injuries directly result in nutrient imbalance) or (2) caused by environmental/ behavioral factors associated with decreased nutrient intake/ delivery (or both). Environmental factors that result in malnutrition or negatively affect its remediation often involve socioeconomic conditions associated with inadequate food availability or complicating behavioral disorders such as anorexia and food aversion. Malnutrition is classified as either acute (fewer than 3 months in duration) or chronic (duration of 3 months or more). Chronic malnutrition may manifest with growth deficits, especially diminished height velocity (stunting), which is a hallmark of this condition that may be observed earlier than 3 months in the course of malnutrition. Hospital-acquired malnutrition refers

Table 2. Executive Summary of Recommendations.

Domain	Recommendations
A. Anthropometric variables Relevant variables Reference data Statistical tests to detect deviation from reference/standard	• Record weight, height, body mass index, and mid–upper arm circumference (MUAC), and consider triceps skin fold (TSF) and mid-arm muscle circumference on admission and then serially, using appropriate growth charts. MUAC and TSF require a trained professional to obtain these measurements. • Head circumference must be obtained in infants younger than 2 years. • When feasible, a single trained individual using standardized technique and devices should perform these anthropometric measurements for nutrition assessment in individual patients. • Measure an infant's length supine on a length board until age 2 years, after which time they should be measured upright. For children older than 2 years and unable to stand, consider using an alternative measurement (eg, tibia length, knee height, arm span) for a height proxy. • Weigh infants and children with minimal clothing on scales accurate to at least 100 g. • Use existing technology (beds with accurate scales) to weigh children who are bedridden. • Use the 2006 World Health Organization charts as a population standard against which individual growth and nutrition characteristics should be described for children up to 2 years of age who are measured in the supine position for length. • For children aged 2–20 years, use the Centers for Disease Control and Prevention 2000 charts with a standing height measurement used for plotting. Healthcare centers may use their electronic health records systems to develop an efficient system of documenting and plotting serial measurements against the reference or standard curves. • Use the *z* score to express individual anthropometric variables in relation to the population reference standard. • When assessing nutrition status on admission or first hospital visit, anthropometric parameters should be recorded and plotted on reference/standard age-appropriate curves to obtain the *z* score. • Classify severity of existing/current nutrition state based on cutoffs for individual anthropometric parameters. Specifics of parameters and their cutoffs will be discussed in a separate document.
B. Growth Dynamic changes	• Use dynamic changes in weight and length velocity over time as compared with a single measured parameter. • Use a decline in *z* score for individual anthropometric measurement (eg, a decrease of more than 1) as the indication of faltering growth. This threshold must prompt investigation into the etiology of growth failure and potential interventions. • Details of recommended frequency of measurements and cutoffs for severity will be described in a separate document from the Academy of Nutrition and Dietetics.
C. Chronicity of malnutrition	• Use 3 months as a cutoff to classify duration of malnutrition as acute (<3 months) or chronic (3 months and longer).
D. Etiology of malnutrition and etiology and pathogenesis Underlying illness Mechanism of nutrient imbalance	• When malnutrition is secondary to a disease/injury, use the term *illness-related malnutrition* in the definition and include the specific disease or condition (acute or chronic) if it is directly responsible for nutrient imbalance. • Include a description of the predominant mechanism leading to nutrient imbalance in the definition. Review and include the most common mechanisms for pediatric malnutrition: (a) decreased intake/starvation (eg, fluid restriction, cardiac failure, anorexia nervosa), (b) increased requirement/hypermetabolism (eg, burn injury), (c) excessive losses (chronic diarrhea, burns, proteinuria), and (d) failure to assimilate (absorb or use) the delivered nutrients (eg, malabsorption states). • Include more than one mechanism if mechanisms exist simultaneously. • Recognize the role of inflammation on nutrition status. • Consider including the presence of inflammation in the definition when laboratory parameters such as C-reactive protein and cytokines are conclusive. • Hospital-acquired malnutrition in children is malnutrition that is acquired or worsened after admission to the hospital. Perform nutrition screening at admission to detect children at higher risk of nutrition deterioration during the illness course. • Awareness of nutrition deterioration during hospitalization will highlight the impact of disease on nutrition state and provide opportunities for improvement in hospital system of care. This should be documented as "worsening malnutrition" as soon as it is evident during the illness course.
E. Impact of malnutrition on functional status	• Consider developmental assessment and neurocognitive monitoring in determining the impact of chronic malnutrition in children. • Include lean body mass measurement (by body composition measurement or anthropometric techniques) with some measure of muscle strength as a meaningful and quantifiable expression of outcomes affected by malnutrition in children. • Use validated objective measures of body composition and uniform assessment techniques for muscle strength in children.

Table 3. Main Classification and Definitions/Characteristics of Pediatric Malnutrition.

Class	Definition/Characterization
1. Illness-related malnutrition (severe or moderate)	*Definition*: Illness-related malnutrition (disease/trauma specified), caused by nutrient imbalance and may be associated with one or more negative (ie, adverse or dysfunctional) outcomes. *Etiology*: The associated disease/illness/trauma should be specified. If more than one condition is thought to affect nutrition status, specify the primary and secondary conditions. *Severity*[a]: The severity of malnutrition is based on the degree of deterioration in key anthropometric markers and may be severe (usually with evidence of severe inflammation[b]) or moderate (inflammation not severe). *Mechanism*: Nutrient imbalance resulting from one or more of the following conditions: decreased intake, increased requirement, increased losses, and altered utilization of nutrients. *Chronicity*: May be acute (duration less than 3 months) or chronic (more than 3 months).
2. Non–illness-related malnutrition: caused by environmental/behavioral factors (severe or moderate)	*Definition*: Malnutrition from environmental (starvation/socioeconomic) or behavioral factors, resulting from decreased nutrient intake (lower than required), and may be associated with one or more adverse developmental or physiologic outcomes. *Severity*[a]: The severity of malnutrition is based on the degree of deterioration in key anthropometric markers and may be severe or moderate. *Mechanism*: Nutrient imbalance resulting from decreased intake. *Chronicity*: May be acute (duration less than 3 months) or chronic (more than 3 months).

[a]Severity of malnutrition is determined by anthropometric measurements and the relationship of these parameters with standard/reference charts. The specifics of anthropometric variables and thresholds for classifying the degree of malnutrition will be discussed in a separate document.
[b]The presence or absence of inflammation influences disease-related malnutrition and must be indicated in the definition when improved markers of inflammation become available in the future.

to nutrient imbalance acquired during hospitalization and may occur with or without preexisting malnutrition, or malnutrition that was present prior to hospital admission.

The mechanisms of nutrient imbalance in illness-related malnutrition include decreased nutrient intake, altered utilization, increased nutrient losses, or increased nutrient requirements (hypermetabolism) not matched by intake. These basic mechanisms may be interrelated, and more than one mechanism is often involved. In addition, there is much more to be learned about disease-specific disruptions of normal metabolic pathways in acute and chronic illness. It is anticipated that the definition of malnutrition will continue to evolve with improved understanding of the diverse processes that lead to and complicate the treatment of this condition. It is widely believed, for example, that the presence and severity of inflammation influence illness-related malnutrition and should be included in its definition. However, the precise role of inflammatory processes in the evolution and treatment of pediatric malnutrition awaits further research in disease-specific pathophysiology as well as the development of specific and cost-effective measuring tools. Children with malnutrition are expected to fall into 1 of the 2 main categories described in Table 3.

Finally, a meaningful definition of malnutrition must include a quantifiable continuum of outcomes affected by specific nutrient imbalances. In addition to anthropometric parameters (height, weight, head circumference [HC]), suggested outcomes affected by malnutrition include achievement of age-appropriate developmental milestones, lean body mass measurements, muscle strength, immune function or dysfunction, frequency or severity of acquired infections, wound healing, length of hospitalization, and disease-specific resource utilization. Reaching consensus on a definition of pediatric malnutrition should permit future research to focus on the impact of malnutrition on pediatric functional outcomes and will help solidify the scientific basis for evidence-based nutrition practices.

Background

The World Health Organization (WHO) defines malnutrition as "the cellular imbalance between the supply of nutrients and energy and the body's demand for them to ensure growth, maintenance, and specific functions."[8] This dynamic imbalance of nutrients affects children differently than adults and can have profound implications for the developing child. A uniform definition of pediatric malnutrition is desirable. At the outset, the working group identified key concepts or domains that would be incorporated in the pediatric malnutrition definition. These 5 domains—anthropometric parameters, growth, chronicity of malnutrition, etiology and pathogenesis, and developmental/functional outcomes—were included in the overall construct of the definition. The distinction between acute and chronic malnutrition may have important bearing on the interventional strategy used in its management. Hence, the chronicity of the nutrient imbalance must be accounted for in a definition. Screening for malnutrition on admission to a healthcare facility or at the beginning of an illness allows

Table 4. Key Domains for Literature Search and Potential Inclusion in the Definition for Pediatric Malnutrition.

Domain	Questions to Address
A. Anthropometric variables Relevant variables Reference data Statistical tests to detect deviation from reference/standard	1. What anthropometric variables should be measured when assessing nutrition status in hospitalized children? 2. Which reference data (National Center for Health Statistics vs World Health Organization growth curves) should be used to plot the individual measurements? 3. Which statistical method should be used to classify nutrition status as deviation from population central tendency? (SD, percentile, or *z* score)
B. Growth Dynamic changes	1. What are the objective parameters for detecting abnormal growth (eg, crossing percentiles, change in *z* -score for anthropometric variable)?
C. Chronicity of malnutrition	1. How is malnutrition classified based on duration: acute vs chronic?
D. Etiology of malnutrition and etiology and pathogenesis	1. What is the impact of underlying illness/injury on nutrition status? 2. What are the potential mechanisms leading to nutrient imbalance? 3. What is the relationship between inflammation and nutrition status? 4. Was malnutrition present at admission? If so, has there been deterioration of nutrition status during this hospital stay?
E. Impact of malnutrition on functional status	1. What are the adverse outcomes affected by pediatric malnutrition?

assessment of current nutrition status and facilitates early detection of subsequent nutrition deterioration related to the illness. Disease type and severity is an important variable that dictates nutrient needs and the ability to deliver and assimilate nutrients. Furthermore, there is increasing recognition of the prevalence of disease-related malnutrition that includes an inflammatory component.[9] The complex interplay between inflammation and nutrition is not well characterized in children, but contemporary definitions of malnutrition will need to account for the impact of inflammation on nutrition status. Finally, no definition of malnutrition is complete without addressing its impact on functional outcomes. The myriad effects of macronutrient and micronutrient deficiencies on outcomes such as growth, body composition, muscle strength, intellectual and developmental ability, and overall quality of life are perhaps most important in the pediatric age group.

Method

The Pediatric Malnutrition Definitions Workgroup was formed in April 2010, and members were assigned the task of reviewing existing pediatric age group English-language literature published between 1955 and 2011. Identified studies were also searched for relevant references related to the 5 domains of the definition that were determined a priori. Each domain was subdivided into concepts and questions (see Table 4). Keywords used for searches generally included *pediatrics, nutrition, malnutrition*, and *undernutrition* and then, specifically for each of the domains, the following:

A. Anthropometric variables: weight, weight loss, height, HC, body mass index (BMI), body composition, nutrition screening and assessment, nutrition history, anthropometrics, survey, muscle mass, fat-free mass, lean body mass, and intake
B. Growth: growth charts, WHO, Centers for Disease Control and Prevention (CDC), wasting, and stunting
C. Chronicity of malnutrition: chronic vs acute malnutrition, hospital length of stay, growth charts and curves, height stunting over time, weight loss over time, and lean body mass loss over time
D. Etiology and etiopathogenesis: disease state, socioeconomic status, poor intake, malabsorption, pathophysiology of pediatric malnutrition, energy balance, inflammation, congenital defects, acute inflammatory (injury, infection, etc), chronic inflammatory disease, child nutrition disorders/etiology, malabsorption, and abnormal nutrient distribution
E. Functional status: developmental delays, muscle function, cognitive abilities, growth and development, behavior, cognition, strength, social ability, muscle strength, hand strength, pinch strength, performance, hand grip strength (HGS), maximal HGS, dominant hand maximal HGS, peak power, force plate, loss, accrual, muscle motor function, motor skills, cognition, cognitive development, schooling, grade, IQ score, intelligence, IQ, cognitive, Binet or Raven or Peabody, and neuropsychological function

The best available literature starting with primary references was obtained and carefully reviewed. Any prospective randomized controlled trials (RCTs), controlled cohort studies, or systematic reviews were analyzed. Evidence tables were formatted to display the evidence for each domain to guide the definition

Table 5. Historical Malnutrition Classification Schemes: Anthropometry.

Classification	Variable	Grade	Definition
Gomez et al[10]	Median WFA (%)	Mild (grade 1) Moderate (grade 2) Severe (grade 3)	75%–90% WFA 60%–74% WFA <60% WFA
Waterlow (wasting)[13]	Median WFH (%)	Mild Moderate Severe	80%–89% WFH 70%–79% WFH <70% WFH
Waterlow (stunting)[13]	Median HFA (%)	Mild Moderate Severe	90%–94% HFA 85%–90% HFA <85% HFA
WHO (wasting)	WFH (*z* scores below median WFH)	Moderate Severe	*z* score between −2 and −3 *z* score <−3
WHO (stunting)	HFA (*z* scores below median HFA)	Moderate Severe	*z* score between −2 and −3 *z* score <−3
Kanawati and McLaren[18]	MUAC/HC	Mild Moderate Severe	<0.31 <0.28 <0.25
Cole et al[30]	BMI (BMI *z* scores for age)	Grade 1 Grade 2 Grade 3	BMI *z* scores for age <−1 BMI *z* scores for age <−2 BMI *z* scores for age <−3

BMI, body mass index; HC, head circumference; HFA, height-for-age; MUAC, mid–upper arm circumference; WFA, weight-for-age; WFH, weight-for-height; WHO, World Health Organization.

development. Recommendations were provided on the scope of each of these domains based on available evidence and by an iterative process to arrive at a multidisciplinary consensus.

Results

The following sections summarize the results of the literature reviews and summary recommendations to the questions developed in the 5 domains.

Domain A: Anthropometric Variables for Assessing Nutrition Status

Question A1. What anthropometric variables should be measured when assessing nutrition status in hospitalized children?
Assessment of malnutrition involves accurate measurements of anthropometric variables such as weight and length/height, which are plotted on population growth curves against which an individual child is compared.[10] However, there remains considerable controversy regarding the most useful measurement and inconsistency in the anthropometric parameters used, or the statistical measures employed to characterize the individual nutrition state. Table 5 summarizes some of the classification schemes for pediatric malnutrition.

In 1956, Gomez et al[11] introduced a classification of malnutrition based on weight below a specified percentage of median weight-for-age. To distinguish stunting (chronic malnutrition) from wasting (acute malnutrition), the calculation of height-for-age was introduced.[12] In 1977, Waterlow et al[13,14] recommended the use of percentiles and standard deviations (SDs) below the median to define underweight, wasting, and stunting. These definitions with subsequent WHO modifications continue to be used widely. Table 6 includes studies that have described the use of anthropometric parameters for defining and classifying pediatric malnutrition.

However, accurate serial weight and height measurements are challenging to obtain in hospitalized children. Obtaining serial weights and heights is generally a low priority. Also, a large proportion of patients do not have these measurements recorded during their course in the hospital.[15] Furthermore, acute illness is often associated with fluid retention and edema that make weight measurements unreliable. In addition to daily fluid shifts, the accuracy of measurements would be affected by dressings, tubing, and other equipment required for care. Critically ill children are often deemed too ill to be moved for weight measurements. The use of in-bed scales may allow accurate serial weighing in this population, especially in infants and neonates.[16,17] As a result, alternative anthropometric tools have been proposed for assessing malnutrition. Mid–upper arm circumference (MUAC) has been suggested as a proxy for weight and HC as a proxy for height.[18] In the patients with fluid shifts and edema, MUAC may be a better indicator than weight-for-height for classification of acute malnutrition.[19] MUAC changes little during the early years. It is simple and accurate, and it predicts malnutrition-related mortality with reasonable specificity and sensitivity.[19-24] Prospective studies in Asia have reported that MUACs of <110 mm predict the risk of death from malnutrition within 6 months.[23] Mid-arm muscle circumference (MAMC) may be calculated from MUAC and triceps

Table 6. Studies Describing the Use of Anthropometric Parameters for Pediatric Malnutrition Definition.

Author and Year	Study Design, Quality	Population, Setting, N	Study Objective	Results	Comments
Salvatore et al,[104] 2010	Review	Cystic fibrosis, North America	Useful malnutrition parameters	BMI percentile associated with pulmonary function	Specific disease process but good data on outcomes and BMI percentile
Lucidi et al,[105] 2009	Prospective, medium	Cystic fibrosis, Europe N = 892	Parameters compared to assess nutrition	BMI percentile best parameter, correlated with lung function	Specific disease but BMI percentile correlated with outcomes
Hirche et al,[106] 2009	Retrospective, medium	Cystic fibrosis, Europe N = 4577 (3849 controls)	Value of calculating a %IBW	%IBW not useful as a marker of nutrition status	Negative study; showed methodological flaws with %IBW calculations
Olsen et al,[51] 2007	Retrospective, medium	FTT, Europe N = 4641	Parameters to define FTT	None of the 7 anthropometric parameters accurately diagnosed FTT	For FTT, single anthropometric measurement not reliable for all age groups
Shet et al,[107] 2009	Retrospective, medium	HIV, India N = 248	Risk factors for mortality in HIV-infected children	Malnutrition is associated with anemia	Multivariate analysis done, but HIV infected tended to be anemic and malnourished
Manary and Sandige,[108] 2008	Review	Mixed, global	Management of acute malnutrition	W/H *z* score to define, MUAC useful, edema in severe	General review
Akinbami et al,[109] 2010	Prospective, high	Mixed, Africa N = 164	Nutrition markers and hospital outcome	MUAC and BMI *z* score <–2 predicted mortality	Parameters assessed for hospital outcomes
Bejon et al,[110] 2008	Prospective, high	Mixed, Africa N = 13,307	Nutrition markers and hospital outcome	MUAC *z* score best, BMI *z* score <–3 okay predicted hospital mortality	Parameters assessed for hospital outcomes
Van den Broeck et al,[111] 1996	Prospective, medium	Mixed, Africa N = 4238	Nutrition markers and eventual mortality	MUAC best, weight for height better if use *z* score <–0.75	Mortality outcome after 30 months; done in primarily younger age group
Mezoff et al,[112] 1996	Prospective, medium	RSV in ICU, North America N = 25	Nutrition markers and hospital outcome	Screen (W/H, disease, CBC, serum albumin) predicted LOS and time on O_2	Combo screen assessed for hospital outcomes, low N
Mahdavi et al,[113] 2009	Prospective, high	Mixed, Middle East N = 140	SGA vs objective measures	SGA (weight Δ, diet, GI, functional, disease) identified malnourished	SGA sensitivity good, specificity poor
Hulst et al,[85] 2010	Prospective, high	Mixed, Europe N = 424	Strong screen validation	Strong screen (subjective, disease, intake/loss, weight Δ) predicted prolonged stay	Screen great sensitivity for outcome
Sermet-Gaudelus et al,[83] 2000	Prospective, high	Mixed, Europe N = 296	Nutrition risk score validation	Risk score (diet, pain, disease) predicted hospital weight loss	High score predicted weight loss in hospital
Oztürk et al,[114] 2003	Prospective, medium	Mixed, Middle East N = 170	Nutrition markers and hospital outcome	BMI and TSF if low at admittance predicted hospital weight loss	Parameters assessed for hospital outcome
Campanozzi et al,[87] 2009	Prospective, high	Mixed, Europe N = 496	Nutrition markers and hospital outcome	BMI *z* score <–2 predicted hospital weight loss	BMI predicted hospital outcome

BMI, body mass index; CBC, complete blood count; FTT, failure to thrive; GI, gastrointestinal; HIV, human immunodeficiency virus; IBW, ideal body weight; ICU, intensive care unit; LOS, length of stay; MUAC, mid–upper arm circumference; RSV, respiratory syncytial virus; SGA, small for gestation age; TSF, triceps skin fold; W/H, weight-for-height.

skin fold (TSF) using the formula MAMC = MUAC – (TSF × 0.314). TSF alone may be a useful screening variable in children.[25] However, its accuracy in children with extensive muscle wasting may be questionable.[26] The standard of care is to measure recumbent length (also known as supine) for infants and children younger than 2 years and standing height for those older than 2 years. However, it is often difficult (if not impossible) to obtain a standing height with acutely ill children, as well as nonambulatory populations (eg, cerebral palsy). In such cases, there are various methods available for obtaining linear measurements, each with strengths and shortcomings. Many portable length boards can convert into stadiometers and thus could feasibly be used to measure recumbent length for older children (eg, measuring table). Notably, if recumbent length and standing height (ie, stature) are obtained on the same person, there is a difference of approximately 0.8 cm (1/3 inch), with standing height measuring less than recumbent length. Obtaining a recumbent length measurement without proper equipment (ie, measuring tape on a bed) does not yield accurate results. If a measuring table is not available, it is recommended to obtain an alternative proxy measure of height, such as arm span, knee height, or tibia length. An in-depth discussion of each technique is beyond the scope of this article, but additional information can be found in the literature.[27-29]

BMI is calculated as weight in kilograms divided by height in meters squared, and it can be used to express weight adjusted for height. To account for variability by sex and age, BMI in children is compared with sex- and age-specific reference values. BMI cutoffs have been suggested as criteria for defining thinness in children and adolescents.[30] The 17-kg/m^2 thinness cutoff in this study is close to the −2 SD cutoff for wasting. In adolescents with eating disorders, the percentage of expected body weight (EBW) is used clinically for diagnosis of anorexia nervosa and as a threshold for management decisions. A patient with <75% EBW is likely to meet the criteria for severe malnutrition and admission to an inpatient facility.[31,32] However, there are concerns regarding the existing methods used to derive this threshold, as they use different reference data. The use of weight-for-height and BMI does not yield equivalent EBW determinations and may affect clinical decisions.[33] HC is a useful index of nutrition status and brain development and is associated with scholastic achievement and intellectual ability in school-aged children.[34] The long-term effects of severe undernutrition at an early age may result in delayed HC growth, delay of brain development, and decreased intelligence and scholastic achievement, variables that are strongly interrelated. In their study of 96 right-handed healthy high school graduates (mean ± SD age 18.0 ± 0.9 years) born at term, Ivanovic et al[35] examined the interrelationships between head size and intelligence, learning, nutrition status, brain development, and parental head size. In this study, HC and brain volume were negatively correlated with undernutrition during the first year of life.

The validity of individual anthropometric parameters may vary based on the population of children. Hence, a combination of measurements obtained by a trained individual in combination with other clinical parameters should guide nutrition assessment in children. Serial anthropometric measurements are absolutely necessary to assess optimal growth during the course of illness.

Recommendation A1

- Record weight, height, BMI, and MUAC and consider TSF and MAMC on admission and then serially using appropriate growth charts. HC must be obtained in infants younger than 2 years.
- When feasible, a single trained individual (usually a dietitian) using standardized techniques and devices should perform these anthropometric measurements for nutrition assessment in individual patients.
- Measure infants' length supine on a length board until 2 years of age, after which time they should be measured upright. For children older than 2 years and unable to stand, consider using an alternative measurement (eg, tibia length, knee height, arm span) for a height proxy.
- Weigh infants and children with minimal clothing on scales accurate to at least 100 g.
- Use existing technology (such as beds with accurate scales or Hoyer lifts) to weigh children who are bedridden.

These are recommendations for anthropometric parameters that should be incorporated in the definition. Future studies will help further evaluate the importance of each of these variables, including the role of body composition measurements, in defining malnutrition and the response to nutrition interventions.

Question A2. Which reference data (CDC vs WHO growth curves) should be used to plot the individual measurements? The WHO adopted the National Center for Health Statistics (NCHS) classification in 1983 as the international reference to classify children as underweight, wasted, or stunted.[36] The CDC's 2000 percentile curves were developed in an effort to address some of the concerns regarding extrapolation of NCHS data to heterogeneous populations. The charts include a set of curves from birth to 36 months of age and a set for children and adolescents 2–20 years of age. The 2000 CDC growth charts more closely matched the national distribution of birth weights than did the NCHS growth charts and could be used to obtain both percentiles and *z* scores. In 2006, the WHO adopted a new population standard based on an international multicenter study using exclusively breastfed children of diverse ethnic backgrounds from 6 diverse geographical regions: Brazil, Ghana, India, Norway, Oman, and the United States.[37] The WHO Multicentre Growth Reference Study (MGRS) was conducted between 1997 and 2003. The study combined longitudinal follow-up of 882 infants from birth to 24 months with a cross-sectional component of 6669 children aged 18–71 months. The study populations lived in

Table 7. Studies Comparing the Standard Reference Charts for Malnutrition Definition.

Author and Year	Study Design, Quality	Population, Setting, N; Study Objective	Results	Comments
Sikorski et al,[115] 2010	Prospective randomized crossover	Mixed, Ethiopia, N = 55; Moyo chart vs traditional look-up tables	Moyo chart increased diagnostic accuracy, decreased time taken per correct diagnosis, and found to be easier by participants.	
Vesel et al,[41] 2010	Retrospective	Mother-infant pairs in Ghana, India, and Peru, N = 9424 Prevalence of malnutrition using WHO vs NCHS	WHO better predictor of malnutrition, identified more malnutrition in first 6 months of life	Gradual increase in prevalence of malnutrition with WHO, sharp increase in malnutrition after 6 months of age with NCHS
Alasfoor and Mohammed,[116] 2009 (abstract only)	Retrospective	Mixed, Oman; WHO vs NCHS		Differences not consistent across age groups
Wang et al,[42] 2009	Prospective cross-sectional survey	Mixed, China, N = 8041; WHO vs NCHS on nutrition status	WHO found more stunting, NCHS found more underweight except in 0–5 months group	
Isanaka et al,[117] 2009	Prospective	Acute malnutrition, Niger, N = 56,214; WHO vs NCHS in children with acute malnutrition	WHO classified 8 times more children as severely malnourished compared with NCHS.	
Yang and de Onis,[118] 2008	Retrospective	Mixed, global, 271 data points; algorithms for converting NCHS to WHO standards when raw data not available		When raw data not available, algorithms accurately calculate WHO estimates using historical NCHS-based estimates
Nuruddin et al,[119] 2009	Retrospective, medium	Mixed survey, Asia, N = 2584; comparison of growth curves	BMI identification of malnourished	WHO curves identified more as malnourished
Nash et al,[120] 2005	Prospective, medium	Mixed hospitalized, Canadian, N = 548; compare big 3 growth curves	Newest CDC curves defined more children as malnourished.	New curve better for diagnosis

BMI, body mass index; CDC, Centers for Disease Control and Prevention; NCHS, National Center for Health Statistics; WHO, World Health Organization.

socioeconomic conditions favorable to growth, and mothers followed healthy practices such as breastfeeding and not smoking during and after pregnancy. Hence, the new WHO standards depict normal human growth under optimal environmental conditions and can be used to assess children everywhere, regardless of ethnicity, socioeconomic status, or type of feeding. These standards demonstrate that healthy children from around the world who are raised in healthy environments and follow recommended feeding practices have strikingly similar patterns of growth. Weight-for-age, length/height-for-age, weight-for-length/height, and BMI-for-age percentile and *z* score values were generated for boys and girls aged 0–60 months. The WHO charts reflect growth patterns among children who were predominantly breastfed for at least 4 months and were still breastfeeding at 12 months of age. The use of the new WHO growth standards is recommended for infants aged 0–24 months.

For children between the ages of 2 and 5 years, both the new WHO and the CDC 2000 charts are available. The data-gathering techniques for both charts were similar for this age group. To avoid multiple transitions between charts for plotting growth parameters during a child's lifetime, the use of CDC charts for all children 2 years and older is appropriate.[38] The methods used to create the WHO and CDC charts are similar after 24 months of age, and the CDC charts can be used continuously through 19 years of age. Hence, transitioning at age 24 months is feasible because measurements switch from recumbent length to standing height at this age, necessitating the use of new printed charts. Table 7 summarizes studies that have reported the use of growth charts for

definitions of pediatric malnutrition. Some studies have shown that the WHO growth reference curves result in a higher measured prevalence of malnutrition when compared with NCHS standards.[39-43] There is some variability in practice related to correcting for gestational age in premature infants. Most premature infants are expected to catch up with their peers by age 2–3 years. The American Academy of Pediatrics (AAP) policy clarifies the use of "corrected (adjusted) age" for premature infants until 3 years of chronological (postnatal) age.[44] This value is calculated by subtracting the number of weeks of gestation at birth from 40 weeks of gestational age.

Recommendation A2

- Use the 2006 WHO charts as a population standard against which individual growth and nutrition characteristics should be described for children up to 2 years of age who are measured in the supine position for length.
- For children and adolescents (aged 2–20 years), use the CDC 2000 charts with a standing height measurement used for plotting. Healthcare centers may use their electronic health records (EHR) systems to develop an efficient system of documenting and plotting serial measurements against the reference or standard curves.
- Use corrected age (number of weeks/months premature + chronological age) for preterm infants until they are 3 years old.

These recommendations mirror those by the CDC and the AAP. Future studies examining the use of growth charts incorporated in EHRs that allow easy plotting of anthropometric parameters and visual displays of growth are desirable. EHRs may also include prompts for missing anthropometry in hospitalized patients.

Question A3. Which statistical method should be used to classify nutrition status as deviation from population central tendency? A variety of statistical scales are used worldwide to describe anthropometric parameters and diagnose malnutrition in children[45] (Table 8). Percentage of median refers to the ratio of a child's weight to the median weight of a child of the same height in the reference data, expressed as a percentage (eg, if the median weight of the reference data for a particular height is 10 kg, then a child weighing 8 kg is 80% weight-for-height). Percentiles rank the position of an individual's measurement on the reference curves, indicating what percentage of the population will be less or greater than that individual (eg, if 10% of the reference population weighs less than the child being considered, then the child is on the 10th percentile). The *z* scores describe how far (in standard deviation or SD units) a child's weight is from the mean weight of a child at the same height in the reference data. For example, an observation value that has a *z* score of −1 is 1 SD less than the mean on a normal/Gaussian curve of the reference data set. Hence, 34% of the values in the data set are expected to have a *z* score between zero (mean) and −1. z scores have been used for several years now, and the WHO has recommended the use of *z* scores in expressing anthropometric measures, especially when describing groups of subjects.[14] *z* Scores allow more precision in describing anthropometric status than does the customary placement "near" or "below" a certain percentile curve. For example, the phrase "below the third percentile" does not distinguish between a child who is just below this point (whose *z* score may be −2.1) from one with severe growth faltering (whose *z* score may be −3.5 or lower). Similarly, 3% of normal children will weigh less than the third percentile, but a *z* score significantly lower than −2.0 clearly indicates a growth problem. CDC computer programs allow calculations for anthropometric data such as weight-for-height and weight-for-age, which can be expressed as *z* scores without needing extensive manual plotting and calculations. Recent EMRs allow plotting of anthropometric parameters on exact percentiles, and some also provide calculations of *z* scores for values recorded.

Table 8. Summary of Anthropometric Scales.

	z Scores	Percentiles	Percent of Median
Normalized curves	Yes	Yes	No
Extreme values interpreted consistently across age and height spectrum?	Yes	Yes	No
Interpretation of cutoff value consistent across indices?	Yes	Yes	No
Ability to identify children with extreme values?	Good	Poor	Good
Normal distribution of values from a study population?	Yes	No	Yes

Adapted by A.S.P.E.N. with permission from Gorstein J, Sullivan K, Yip R, et al, World Health Organization. Issues in the assessment of nutritional status using anthropometry. *Bulletin of the World Health Organization* 1994;72:273-283, Table 5.[121]

Refer to the appendix for additional resources on determining *z* scores for anthropometrics. When using percentiles or *z* scores, "average" is the median (50th percentile) when percentiles are used, but "average" is the mean when *z* scores are used.

Recommendation A3

- Use the *z* score to express individual anthropometric variables in relation to the population reference standard.
- When assessing nutrition status on admission or first hospital visit, anthropometric parameters

should be recorded and plotted on reference/standard age-appropriate curves to obtain the *z* score. Serial measurements are absolutely necessary for longer hospital stays.
- Classify the severity of existing/current nutrition state based on cutoffs for individual anthropometric parameters. Specifics of relevant parameters and frequency of measurements and their cutoffs will be discussed in a separate document.

Domain B: Growth

Question B1. What are the objective parameters for detecting abnormal growth? Failure to thrive (FTT) is a term used to describe children who are not growing as expected. It is estimated that up to 5 in 100 infants and children in the United States have FTT.[46] Although other factors may be responsible for FTT, more than 90% of cases in most studies do not have an underlying medical cause, and virtually all causes are identified by a careful history and physical exam.[47] Environmental and behavioral causes predominate, and detrimental effects of chronic malnutrition on neurocognitive development are well documented.[48] Recommendations for treating and evaluating children with mild growth deviations in primary care settings and a standardized definition of FTT that warrants more intensive treatment would help ensure that children are referred appropriately and that resources are focused on the highest risk children.[49]

It is generally agreed that growth faltering or FFT should be defined by deterioration in anthropometrical parameters, but there is no consensus regarding the specific anthropometrical criteria.[50] Failure to gain weight is generally used, with a cutoff of around the fifth percentile for weight-for-age.[51] In addition to the above method of using cutoff values for attained growth, it is necessary to assess the progression of growth chronologically when evaluating malnutrition or FTT. When defining FTT based on growth velocity, the most commonly used criterion is "downward crossing of more than two major percentile lines" or "being among the slowest gaining 5% on a conditional weight gaining chart (which compares an infant's current weight with that predicted from their previous weight)".[52,53] A decrease in weight-for-age z score has been used to define growth failure and as an outcome measure in several recent studies.[54,55] A decrease in weight-for-age of more than 0.67 *z* score during the first months after surgery for congenital heart defects, corresponding to a downward percentile crossing through at least one of the displayed percentile lines on standard growth charts, is strongly related to late mortality in children undergoing cardiac surgery.[56] In contrast, long-term surviving children showed a mean increase in weight-for-age *z* scores after the final operation. Hence, there is increasing use of *z* scores and changes in *z* scores for anthropometric measurements. There seems to be a trend toward using *z* scores as a uniform strategy to define and classify malnutrition and growth failure for the purposes of scientific investigation and community interventional programs.

Although recommendations for the frequency of obtaining serial anthropometric measurements are available, these need to be further reviewed before uniform application. A potential problem in the hospital setting could be the lack of access to historical data to determine growth patterns. EHRs may help to bridge this gap in information across different settings. Until such measures are in place, the ability of the hospital-based clinicians to evaluate trends in anthropometric parameters may be limited in some patients.

Recommendation B1
- Use dynamic changes in weight and length velocity over time as compared with a single measured parameter.
- Use a decline in *z* score for individual anthropometric measurement (eg, a decrease of more than 1) as the indication of faltering growth.
- The threshold for anthropometric deterioration must prompt investigation into the etiology of growth failure and potential interventions.

Domain C: Chronicity of Malnutrition—Acute vs Chronic

Question C1. How is malnutrition classified based on duration: acute or chronic? Acute malnutrition results in weight decline that is hallmarked by a decrease in the patient's weight-for-height. Chronic malnutrition is most often identified by a faltering height-for-age and affects long-term growth as a result of chronic nutrition deficiency.[57] The distinction between acute and chronic illness is based on time. The NCHS (www.cdc.gov/nchs/ich.htm) defines *chronic* as a disease or condition that lasts 3 months or longer. Chronic malnutrition may be characterized by stunting (decreased height velocity). This is a characteristic of chronic malnutrition that may be irreversible and manifest earlier than 3 months if nutrient deficiency is severe.

Recommendation C1
- Use 3 months as a cutoff for delineation between acute (<3 months) or chronic (≥3 months) malnutrition.
- Chronic malnutrition may be characterized by height-for-age (HFA) that is less than −2 *z* scores.

Domain D: Etiology and Pathogenesis of Malnutrition

Question D1. What is the impact of underlying illness on nutrition status? The prevalence of malnutrition varies depending on the underlying medical conditions, ranging from 40% in patients with neurologic diseases to 34.5% in those with infectious disease, 33.3% in those with cystic fibrosis, 28.6% in those with cardiovascular disease, 27.3% in oncology patients, and 23.6% in those with GI diseases.[5] Patients with multiple

diagnoses are most likely to be malnourished (43.8%). In a population of children scheduled for elective surgery in a tertiary referral hospital, 51% of children were malnourished.[6] In their study of 424 children aged 30 days or older, Joosten et al documented a prevalence of 11% acute malnutrition and 9% chronic malnutrition upon admission to the hospital.[58] The strongest predictor of malnutrition upon admission was the presence of underlying disease. Children with acute malnutrition had a longer hospital length of stay than those without. In this study, malnutrition was determined by the presence of any one of the following cutoffs: (a) weight-for-height (WFH) SD score lower than −2, (b) WFH less than 80% of the median, (c) % ideal body WFH less than 80%, (d) WFH less than fifth percentile, or (e) BMI SD score of less than −2. A uniform definition of malnutrition is expected to provide a more accurate prevalence of malnutrition in children and hence allow determination of the impact of specific disease states on nutrition status. Table 9 summarizes studies demonstrating the impact of specific diseases on nutrition status in children.

Children with CHD have a high incidence of protein-energy malnutrition (PEM), which contributes to the poor outcome in this cohort.[59] Common reasons for energy deficits in children with CHD include decreased intake, increased energy expenditure (attributable to cardiac failure or increased work of breathing), and malabsorption (attributable to increased right-sided heart pressure, lower cardiac output, or altered gastrointestinal function).[60-62] Longer hospital length of stay and frequency of readmission were significantly correlated with poor nutrition status in children with single-ventricle physiology, and aggressive enteral nutrition (EN) and parenteral nutrition (PN) were associated with better nutrition status. Patients in this study demonstrated continued nutrition deterioration over time, and a majority were severely underweight at the time of subsequent hospitalization for major cardiac surgery.[63] Studies with aggressive nutrition interventions and home monitoring programs are currently under way by facilities through the National Pediatric Cardiology Quality Improvement Collaborative.

Children with burn injuries manifest a prolonged hypermetabolic stress response, with a catabolic state that can persist for weeks after the initial injury. Poor intake in this group results in energy deficits, and the negative effects of energy deficit on nutrition status may persist for months after injury. Decrease in lean body mass has been shown for up to a year after the burn injury, with delayed linear growth reported for up to 2 years after burn injury.[64,65] One in every 5 children admitted to the pediatric intensive care unit (PICU) experiences acute or chronic malnutrition.[59,66,67] The increased energy demands secondary to the metabolic stress response to critical illness, failure to prescribe adequate nutrients, and delay or failure to administer the prescribed nutrients are factors responsible for the subsequent deterioration of nutrition status in children admitted to the PICU. Therefore, acute and chronic malnutrition have been shown to worsen at discharge from the PICU.[59] Several other groups of patients are deemed at a higher risk of malnutrition, including children with cystic fibrosis, oncologic illnesses, GI diseases, and neurologic impairment. Eating disorders represent the third most common chronic disease in adolescents after obesity and asthma. Recently, hospitalizations for children younger than 12 years with eating disorders have increased significantly. Eating disorders may indeed be biologically based and probably constitute a major cause of undernutrition in the pediatric age group in industrialized nations.

Hence, the definition of malnutrition must include specific conditions that contribute to the nutrition state. The mechanisms responsible for nutrient deficits in these patients may vary.

Recommendation D1

- Include the specific disease condition in the malnutrition definition if it is directly responsible for energy and/or protein imbalance.

For example, a patient with a burn injury resulting in acute deterioration of nutrition status should be classified as having burn-related acute malnutrition.

Question D2. What are the potential mechanisms leading to the nutrient imbalance? Malnutrition is the result of an imbalance between nutrient requirement and intake/delivery. A variety of mechanisms may alter this balance in hospitalized children. Malnutrition typically occurs along a continuum of inadequate intake and/or increased requirements, impaired absorption, and altered nutrient utilization. Weight loss or impaired growth can occur at multiple points along this continuum. Individuals may also present with inflammatory, hypermetabolic, and/or hypercatabolic conditions. Table 10 summarizes studies in which some of these mechanisms are elucidated.

Recommendation D2

- Include a description of the most predominant mechanism leading to nutrient imbalance in the definition. Review and include the most common mechanisms for pediatric malnutrition: (a) decreased intake/starvation (eg, fluid restriction, cardiac failure), (b) increased requirement/hypermetabolism (eg, burn injury), (c) excessive losses (chronic diarrhea, protein-losing enteropathy, burns, proteinuria), and (d) failure to assimilate (absorb or usze) the delivered nutrients (eg, malabsorption states, cystic fibrosis, short bowel syndrome).
- Include more than one mechanism if mechanisms exist simultaneously.

Question D3. What is the relationship between inflammation and nutrition status? Inflammatory conditions may increase requirements for nutrients while promoting a nutrient-wasting catabolic state. Illness-related malnutrition is associated with an inflammatory component. Inflammation promotes

Table 9. Malnutrition in Different Disease States.

Author and Year	Study Design, Quality	Population, Setting, N	Study Objective	Results	Comments
Delgado et al,[79] 2008	Retrospective, fair	PICU in Brazil, N = 29	Determine incidence of malnutrition in first 72 hours after admission to a PICU	Of 1077 patients, looked at 2 subgroups—malnutrition and normal No difference in mortality, LOS, sepsis Both groups had similar IL-6 levels on days 1 and 5.	No significant change: weight-for-age *z* score (–2 = moderate/severe malnutrition) Looked at CRP, IL-6, serum albumin, LOS, mortality, upper arm muscle circumference on days 1, 5, and 10
Dylewski et al,[122] 2010	Retrospective, weak	Pediatric burn patients with ≥20% TBS, N = 36	Determine incidence of malnutrition among international burn patients transferred to a burn center 21–61 days postinjury	61% incidence of malnutrition MN patients transferred later postinjury than normal nutrition status patients. No difference in infections	Malnutrition defined as >10% weight loss compared with preinjury weight, visible cachexia (loss of LBM).
Fischbach et al,[123] 2009	Review, fair	Pediatric patients on hemodialysis	To explain the conditions contributing to malnutrition in this population	MN in pediatric hemodialysis patients a result of chronic acidosis, inflammation, insulin resistance, ↑ glucocorticoid production, and ↑ angiotensin II Poor appetite may be secondary to all of this.	Cachexia—loss of LBM—may be related to protein metabolism. Daily hemodialysis can improve growth in this population.
Galati et al,[124] 2011	Cohort study using age-matched controls, good	Pediatric oncology unit in Brazil N = 16 children with cancer and 19 without	To describe the energy expenditure and substrate utilization of children with cancer compared with age-, sex-, and BMI-matched controls	No difference in energy expenditure or substrate utilization between groups No difference in food consumption	Used indirect calorimetry, BIA, dietary recall, height, weight, BMI, vitamin levels
Srivaths et al,[125] 2010	Cross-sectional, good	Pediatric patients on hemodialysis unit, N = 16	To assess for an association between inflammation, malnutrition, renal osteodystrophy, and coronary calcification	High prevalence of coronary calcification mostly related to how long patient was on hemodialysis and calcium/phosphate product. Malnutrition and inflammation were not shown to be associated with coronary calcification in this study; patients did have ↑ IL-6 levels; BMI *z* scores −0.31 to −0.33.	Measured IL-6, CRP, serum albumin, cholesterol, BMI, *z* score, nPRC rates
Walters et al,[126] 2009	Review, fair	Pediatric Crohn's disease	To review the contributing factors to malnutrition in this population	Children with Crohn's disease have impaired growth from undernutrition, proinflammatory cytokines, disruption of IGF-1 pathways, steroid use, TNF, and impaired absorption of nutrients.	Did not really quantify or categorize malnutrition—just discussed contributing and interplaying factors
Mak et al,[127] 2005	Review	CKD	Understanding molecular mechanism of cachexia in CKD	Leptin may play role in pathogenesis of uremic anorexia and cachexia. Increased concentrations of proinflammatory cytokines; may exacerbate loss of skeletal muscle	Malnutrition is different from cachexia. Malnutrition is abnormalities caused by inadequate diet. Cachexia is loss of body weight with muscle mass being replaced by fat and declining serum proteins.

BIA, bioelectric impedance; BMI, body mass index; CKD, chronic kidney disease; CRP, C-reactive protein; IGF-1, insulin-like growth factor 1; IL-6, interleukin-6; LBM, lean body mass; LOS, length of hospital stay; MN, malnutrition; nPCR, normalized protein catabolic rate; PICU, pediatric intensive care unit; TBS, total body surface; TNF, tumor necrosis factor.

Table 10. Specific Mechanisms Responsible for Nutrient Imbalance.

Author and Year	Study Design, Quality	Population, Setting, N	Study Objective	Results	Comments
Listernick,[128] 2004	Case study/ expert opinion	N = 1 FTT, North America	Expert critique of 1 FTT case	Accurate feeding history is essential to diagnosing FTT. Review of the growth pattern can help identify etiology of FTT (eg, inadequate kcal intake).	Good overview differentiating PEM as kwashiorkor vs marasmus Kwashiorkor edematous and 60%–80% of expected Marasmus <60% of expected WFA; if these children have edema, they have marasmic-kwashiorkor
Olsen et al,[51] 2007	Prospective, large	N = 5624 Born in Copenhagen in 2000	Compare prevalence and concurrence of FTT using 7 anthropometric criteria; test sensitivity and PPV in detecting "significant undernutrition" (defined as combination of slow conditional weight gain and low BMI)	27% of infants met 1 or more criteria for FTT in at least 1 of the 2 age groups (2–6 months vs 6–11 months). Concurrence among the 7 criteria was poor. All 7 criteria had low PPV. No single measurement reliably identified nutrition growth delay in the general population.	Combining deceleration in weight gain with low weight for length seems a theoretically valid definition of significant undernutrition.
Goulet,[129] 2010	Review	FTT, Europe	Useful malnutrition parameters	No consensus for FTT definition Definition of FTT and its risk factors depend on the anthropometrics used. Common cause of poor growth is inadequate intake, especially energy and protein, but also some micronutrients. PEM is caused by imbalance between protein energy requirements and intakes during illness.	
Mak et al,[127] 2005	Review	CKD, United States	Understanding molecular mechanism of cachexia in CKD	Leptin may play role in pathogenesis of uremic anorexia and cachexia. As renal function decreases, there are increased concentrations of proinflammatory cytokines; this may exacerbate loss of skeletal muscle independent from hepatic activation of the acute phase response.	Malnutrition is different from cachexia. Malnutrition is a misleading diagnosis in CKD and ESRD and suggests that the solution is supplying more food or altering composition of diet. Malnutrition is abnormalities caused by inadequate diet. Cachexia is loss of body weight with muscle mass being replaced by fat and declining serum proteins.

(continued)

Table 10. (continued)

Author and Year	Study Design, Quality	Population, Setting, N	Study Objective	Results	Comments
Dodge and Turck,[130] 2006	Review	CF, Europe	Discuss nutrition implications of CF and management	Increased REE and energy intake are too low to compensate. Chronically malnourished children have slowed or cessation of linear growth (stunting) vs adults who primarily exhibit wasting. Anthropometrics should be obtained at least every 3 months. Failure to maintain weight or growth velocity should be immediately addressed. Those with BMI <25th percentile are at nutrition risk. BMI <10th percentile is defined as nutrition failure; treatment is mandatory.	
Gahagan,[131] 2006	Review/case study	FTT, United States	Review diagnostic and treatment approaches for common presentations of FTT	Conditions that put children at risk for poor growth: poverty and food insecurity Three mechanisms for pathogenesis of poor growth: 1. Loss of kcal via malabsorption 2. Increased kcal expenditure 3. Inadequate intake of kcal	FTT defined as failing to grow at a rate consistent with expected standards for infants and toddlers <3 years. Wasting is decreased WFH and decreased subcutaneous fat, indicative of acute malnutrition. Stunting is decreased HFA and can be a sign of chronic malnutrition. Figure 3 is excellent—differential diagnosis of FTT.
Viteri,[132] 2010	Review/ prospective, double-blind pilot study	Fully recovered, previously malnourished children, Central America and Panama (INCAP)	Effect of different sources of protein on nitrogen balance and requirements of essential AA Effects of different energy intakes on nitrogen balance Effect of activity on linear growth and lean body mass repletion	Habitual Central American diet providing 80–85 kcal/kg/d meets needs of well-nourished children and allows catch-up growth at 95–105 kcal/kg/d (presuming no infections). Nutritionally induced or disease-induced inactivity contributes to stunting; physical activity allows normal or catch-up growth in young undernourished, stunted children.	Stunting is a universal finding among children with mild to moderate PEM (or could have had PEM when <5 years of age). Mechanism for stunting is not known.

BMI, body mass index; CF, cystic fibrosis; CKD, chronic kidney disease; ESRD, end-stage renal disease; FTT, failure to thrive; HFA, height-for-age; PEM, protein energy malnutrition; PPV, positive predictive value; REE, resting energy expenditure; WFA, weight-for-age; WFH, weight-for-height.

skeletal muscle breakdown, mediated by a cytokine-driven pathway.[68,69] Critical illness or injury promotes an acute inflammatory response that has a rapid catabolic effect on lean body mass.[70] The acute phase inflammatory response is associated with elevated resting energy expenditure and nitrogen excretion and thereby energy and protein requirements, respectively. Nutrition supplementation alone only partly reverses or prevents muscle protein loss in active inflammatory states.[71] The anorexia that accompanies inflammation will promote further loss of lean tissue if nutrition intake is inadequate. Over the past decade, it has become increasingly evident that the pathophysiology of disease or injury-associated malnutrition invariably includes acute or chronic inflammation that affects body composition and biological function.[68]

The inflammatory condition may be short-lived or chronic in nature with the severity being influenced by the progression and extent of underlying illness/disease condition. Loss of muscle mass and function may occur insidiously in the chronic disease state over months to years. It is important to recognize the presence or absence of a systemic inflammatory response in the malnourished state, as it affects the response to intervention. In the absence of inflammation, as seen in malnutrition due to starvation, appropriate nutrient interventions may be successful in treating malnutrition. On the other hand, the presence of inflammation may limit the effectiveness of nutrition interventions, and the associated malnutrition may compromise the clinical response to medical therapy. If inflammation is present, then it is useful to clarify whether it is mild, moderate, or severe and transient or sustained. The recently proposed adult malnutrition definition has suggested that acute disease-related malnutrition is probably associated with a severe degree of inflammation and chronic disease-related malnutrition with a mild to moderate degree of inflammation.[68,72] However, the role of inflammation and currently available inflammatory markers, such as C-reactive protein (CRP) or erythrocyte sedimentation rate, in classifying pediatric malnutrition severity has not been adequately described.

Inflammatory cytokines can impair growth via multiple pathways. Anorexia, skeletal muscle catabolism, and cachexia affect the growth plate via insulin-like growth factor 1 (IGF-1)–independent or IGF-1–dependent pathways.[73-75] The inhibitory effects of tumor necrosis factor–α (TNF-α) and interleukin (IL)–1β on the growth plate are reversed by anti–IL-1β and anti–TNF-α.[75] The effect of TNF-α on IL-6 transcription and circulating leptin level may be reversed by infliximab.[76,77] In pediatric Crohn's disease, growth retardation may result from a complex interaction between nutrition status, inflammation, disease severity, and genotype, which causes resistance to the effects of growth hormone.[78] Elevated serum concentration of CRP is one of the most common nontraditional markers used to stratify cardiovascular risk, and it has been used to identify patients with chronic inflammation as it reflects a proinflammatory state. IL-6 concentrations may be an important marker of early inflammatory response with serial levels correlating with nutrition status in critically ill children.[79] Although there is no doubt about the association between inflammatory state and nutrition recovery, the precise nature of this relationship remains elusive. Furthermore, despite evidence of a key role for the inflammatory cytokines such as TNF-α, IL-6, and IL-1β, these are not routinely measured outside the research setting. The list of clinical inflammatory markers currently used in practice is at best rudimentary, and their relevance in malnourished states needs to be examined. Research efforts aimed at examining the validity of newer biomarkers of the inflammatory state are urgently needed.

Recommendation D3

- Recognize the role of inflammation on nutrition status.
- Include the presence of inflammation with available laboratory parameters such as CRP and cytokines in the definition.

Future studies examining biomarkers of inflammation and the impact of the inflammatory state on malnutrition in children are highly desirable.

Question D4. Is there a distinction between malnutrition at admission vs malnutrition acquired during the hospital stay?
The nutrition status of children often declines after admission to the hospital, resulting in early and serious consequences, such as slowing of growth and increased susceptibility to various infections. This has mainly been attributed to the poor awareness and the lack of education of healthcare providers and adverse hospital routines.[80] Children with severe acute illness or severe trauma often experience extreme metabolic stress. Although "on admission," these patients often present without a prior history of malnutrition, the presence of the massive inflammatory response seen in the acute phase of injury or critical illness limits the effectiveness of nutrition interventions and can contribute to the rapid development of malnutrition. Periods of interrupted feeding, imposed to accommodate the variety of medical-surgical interventions needed to stabilize these patients, also contribute to the development of malnutrition despite the clinician's best efforts to provide adequate energy and other nutrients.[81,82] Although malnutrition acquired after admission to the hospital is frequently associated with a risk of adverse clinical events and a longer hospital stay leading to higher healthcare costs, it is a problem that remains largely underestimated and often unrecognized.[58,83-85] In a single-center study at a tertiary hospital in Brazil, more than half of the children lost weight after admission during their hospital stay, and around 10% of well-nourished children became malnourished.[86] In an Italian center, children with an admission BMI-for-age *z* score lower than −2 SD showed a mean BMI decrease at the end of their hospital stay, which was significantly higher than in

children with better nutrition status at admission.[87] In this study, the investigators defined nutrition deterioration as a drop in the BMI *z* score by 0.25 or more during the hospital stay. One in every 5 children had a significant decrease in BMI *z* scores that was already detectable by the third day after admission. This suggests the possibility of early detection of children who are at risk for worsening malnutrition and the ability to establish an appropriate nutrition management strategy to prevent the development of such adverse conditions during their hospital stay.

There is increasing interest in determining the impact of hospitalization (disease, intervention, nutrition, and other factors during the hospital course) on nutrition status. Hence, a distinction between nutrition state on admission and change in nutrition state or acquisition or worsening of malnutrition during the hospital course is relevant. Admission assessment will allow identification of malnourished patients and provide opportunities to prioritize nutrition interventions in this group. Serial nutrition assessments during the hospital stay will help identify those with subsequently worsening nutrition status. Heightened awareness, multidisciplinary approach, and prioritization of sound nutrition practices may help decrease some of the preventable causes of acquired or worsening malnutrition.

Recommendation D4

- Perform nutrition screening at admission to detect children at higher risk of nutrition deterioration during the illness course. Awareness of nutrition deterioration during illness will highlight the impact of disease on nutrition state and provide opportunities for improvement in care at a system level.

Domain E: Functional Status

Question E1. What are the functional outcomes affected by pediatric malnutrition? A well-known consequence of malnutrition is muscle dysfunction, as reflected by decreased grip strength.[88,89] HGS correlates with the loss of total body protein and has been shown to be a good marker of immediate postoperative complications and predictive of major complications in adult cirrhotic outpatients.[89] Decreased HGS is also a predictor of loss of functional status in hospitalized patients.[88] Recent observations in healthy children aged 6–18 years have extended our knowledge of normal variation of this characteristic with age, sex, size, and body composition and could be used as a reference pattern.[90] HGS increases with age, and a significant sexual dimorphism from age 12 years is observed. HGS detects a high prevalence of nutrition risk in patients with cirrhosis and Crohn's disease in remission.[89,91] However, the use of HGS in pediatric populations is limited and may not be feasible in infants and younger children. Pediatric studies that evaluate the use of HGS or similar measures of muscle function in nutrition assessment are urgently required.

Lack of adequate macronutrients or selected micronutrients, especially zinc, selenium, iron, and the antioxidant vitamins, can lead to clinically significant immune deficiency and infections in children. Undernutrition in critical periods of gestation and neonatal maturation and during breast milk weaning impairs the development and differentiation of a normal immune system. Infections are both more frequent and more often become chronic in the malnourished child. Micronutrients act as antioxidants and as cofactors at the level of cytokine regulation. Because the immune system is immature at birth, malnutrition in childhood might have long-term effects on health.[92] Optimal nutrition provides nutrients and factors that have been shown to modulate immune maturation and response to inflammation.[93] In addition, enteral nutrients alter gut microflora and may affect antigen exposure. The mechanisms by which early nutrition affects immune responses in childhood need further elucidation.

No aspect of our physical or psychological existence is not affected in some way by nutrition.[94] A profound lack of nutrition would obviously have a negative influence on all aspects of development, and such effects of malnutrition are well documented.[95-97] In a cohort study of 20 children who had been fed a thiamine-deficient infant formula, investigators assessed language, mental development, and motor development. In comparison to matched controls without nutrition deficiency, the children with thiamine deficiency had receptive and expressive language delay, as well as delayed age at independent walking.[98] In individual studies, young children who had FTT followed for up to 8 years had measurable IQ deficits as well as learning and behavioral difficulties.[99,100] A meta-analysis in 2004 suggested that FTT in infants may result in long-term problems in cognitive development with a 4.2 IQ point decrement.[101] Malnourished children also have increased rates of infection and behavioral problems, including impaired communication skills and attention-deficit hyperactivity disorder.[101,102]

Environmental factors such as malnutrition during critical periods may modify the risk for the development of many common diseases later in life.[103] This phenomenon is probably explained by epigenetics, the interindividual variation in DNA patterns. There are scarce data on the critical interrelation between early nutrition, growth, development, and subsequent health and the influence of early nutrition on epigenetic modifications. The role of optimal nutrition in preventing the development of diseases later in life needs further exploration. Malnutrition may also affect other outcomes such as wound healing, length of hospital stay, and resource utilizations. Adverse outcomes must be included in the definition of pediatric malnutrition, and future research examining the impact of malnutrition on relevant clinical outcomes is urgently needed.

Recommendation E1

- Consider developmental assessment and neurocognitive monitoring in determining the impact of chronic undernutrition in children.
- Include lean body mass measurement with some measure of muscle strength as a potentially

identifiable outcome adversely affected by malnutrition in children.
- Use validated objective measurements of body composition and uniform assessment techniques for muscle strength in children.

Future studies aimed at describing the nexus between nutrition state and immunity during illness are urgently required. Biomarkers of immune dysfunction may be incorporated in the definition of nutrition as an outcome in the future.

Pediatric Malnutrition Classification

In summary, pediatric malnutrition (undernutrition) is defined as an imbalance between nutrient requirement and intake, resulting in cumulative deficits of energy, protein, or micronutrients that may negatively affect growth, development, and other relevant outcomes. On the basis of discussions for each domain outlined above, we propose a new framework for defining pediatric malnutrition (see Figure 1). This schema for defining malnutrition incorporates the concepts of chronicity, etiology, and pathogenesis of malnutrition; its relationship with inflammation; and its impact on functional outcomes. Malnutrition for an individual child should be diagnosed based on the anthropometric parameters and their cutoffs. In addition to the anthropometric definition, the new definition of malnutrition will include a diagnostic relationship between what is known about the causative disruption of normal nutrient pathways by the patient's illness or home environment and the presumptive effect (ie, the patient-specific expression of this nutrient imbalance as a negative outcome). This requires the inclusion of specific disease states if such disease(s) has already contributed to or is expected to result in nutrition vulnerability and deterioration. Hence, malnutrition will be characterized as illness related (secondary to disease, condition, surgery, or injury) and/or not illness related (secondary to environmental factors). Occasionally, pediatric malnutrition may be characterized as both illness related and environmental (ie, one may be primary but exacerbated by the other). Furthermore, the specific pathway leading to malnutrition is incorporated in the definition and may include one or more of the following: (a) decreased nutrient intake (starvation), (b) increased requirement of nutrients, (c) increased nutrient losses, and (d) altered nutrient utilization. Finally, one or more anthropomorphic or developmental outcomes is included if deleterious and felt to be a manifestation or cause/effect of the malnourished state. The role of inflammation is acknowledged by indicating its presence along with illness-related malnutrition. Acquired malnutrition is defined as further deterioration of nutrition status of children in relation to their nutrition state on admission.

Appendix

Resources to Calculate z Scores for Anthropometric Parameters

CDC Growth Charts	WHO Growth Charts
STAT GrowthCharts (compatible with iPod Touch, iPhone, iPad)	STAT GrowthCharts WHO (compatible with iPod Touch, iPhone, iPad)
Epi Info NutStat: (available for download) http://www.cdc.gov/growthcharts/computer_programs.htm	WHO *z* score charts: http://www.who.int/childgrowth/standards/chart_catalogue/en/index.html
CDC website: *z* score data files available as tables http://www.cdc.gov/growthcharts/zscore.htm	WHO Multicentre Growth Study website: http://www.who.int/childgrowth/software/en/ All 4 macros (SAS, S-Plus, SPSS, and STATA) calculate the indicators of the attained growth standards.

A.S.P.E.N. Board of Directors Providing Final Approval

Jay Mirtallo, MS, RPh, BCNSP, FASHP; Tom Jaksic, MD, PhD; Ainsley Malone, MS, RD, CNSC; Phil Ayers, PharmD, BCNSP; Praveen S. Goday, MBBS, CNSC; Daniel Teitelbaum, MD; Deborah Andris, MSN, APNP; and Gordon Sacks, PharmD, BCNSP, FCCP.

Acknowledgment

The authors would like to express sincere gratitude to the A.S.P.E.N. Malnutrition and Clinical Practice Committees, the Pediatric Malnutrition Workgroup of the Academy of Nutrition and Dietetics, and the Committee on Nutrition of the American Academy of Pediatrics for their expert review and guidance on this manuscript.

References

1. Pollack MM, Ruttimann UE, Wiley JS. Nutritional depletions in critically ill children: associations with physiologic instability and increased quantity of care. *JPEN J Parenter Enteral Nutr*. 1985;9(3):309-313.
2. Pelletier DL, Frongillo EA Jr, Habicht JP. Epidemiologic evidence for a potentiating effect of malnutrition on child mortality. *Am J Public Health*. 1993;83(8):1130-1133.
3. Pelletier DL, Frongillo EA Jr, Schroeder DG, Habicht JP. The effects of malnutrition on child mortality in developing countries. *Bull World Health Organ*. 1995;73(4):443-448.

4. Hendricks KM, Duggan C, Gallagher L, et al. Malnutrition in hospitalized pediatric patients: current prevalence. *Arch Pediatr Adolesc Med*. 1995;149(10):1118-1122.
5. Pawellek I, Dokoupil K, Koletzko B. Prevalence of malnutrition in paediatric hospital patients. *Clin Nutr*. 2008;27(1):72-76.
6. Secker DJ, Jeejeebhoy KN. Subjective Global Nutritional Assessment for children. *Am J Clin Nutr*. 2007;85(4):1083-1089.
7. Joosten KF, Hulst JM. Prevalence of malnutrition in pediatric hospital patients. *Curr Opin Pediatr*. 2008;20(5):590-596.
8. de Onis M, Monteiro C, Akré J, Glugston G. The worldwide magnitude of protein-energy malnutrition: an overview from the WHO Global Database on Child Growth. *Bull World Health Organ*. 1993;71(6):703-712.
9. Jensen GL, Mirtallo J, Compher C, et al. Adult starvation and disease-related malnutrition: a proposal for etiology-based diagnosis in the clinical practice setting from the International Consensus Guideline Committee. *JPEN J Parenter Enteral Nutr*. 2010;34(2):156-159.
10. Gomez F, Galvan RR, Cravioto J, Frenk S. Malnutrition in infancy and childhood, with special reference to kwashiorkor. *Adv Pediatr*. 1955;7:131-169.
11. Gomez F, Ramos Galvan R, Frenk S, Cravioto Munoz J, Chavez R, Vazquez J. Mortality in second and third degree malnutrition. 1956. *Bull World Health Organ*. 2000;78(10):1275-1280.
12. Seoane N, Latham MC. Nutritional anthropometry in the identification of malnutrition in childhood. *J Trop Pediatr Environ Child Health*. 1971;17(3):98-104.
13. Waterlow JC. Classification and definition of protein-calorie malnutrition. *Br Med J*. 1972;3(5826):566-569.
14. Waterlow JC, Buzina R, Keller W, Lane JM, Nichaman MZ, Tanner JM. The presentation and use of height and weight data for comparing the nutritional status of groups of children under the age of 10 years. *Bull World Health Organ*. 1977;55(4):489-498.
15. Butterworth CE Jr. The skeleton in the hospital closet. *Nutrition*. 1994;10(5):442.
16. Spence K, Smith J, Peat J. Accuracy of weighing simulated infants with in-bed and freestanding scales while connected and disconnected to a ventilator. *Adv Neonatal Care*. 2003;3(1):27-36.
17. Engstrom JL, Kavanaugh K, Meier PP, et al. Reliability of in-bed weighing procedures for critically ill infants. *Neonatal Netw*. 1995;14(5):27-33; discussion 41.
18. Kanawati AA, McLaren DS. Assessment of marginal malnutrition. *Nature*. 1970;228(5271):573-575.
19. Myatt M, Khara T, Collins S. A review of methods to detect cases of severely malnourished children in the community for their admission into community-based therapeutic care programs. *Food Nutr Bull*. 2006;27(3)(suppl):S7-S23.
20. Alam N, Wojtyniak B, Rahaman MM. Anthropometric indicators and risk of death. *Am J Clin Nutr*. 1989;49(5):884-888.
21. Briend A, Dykewicz C, Graven K, Mazumder RN, Wojtyniak B, Bennish M. Usefulness of nutritional indices and classifications in predicting death of malnourished children. *Br Med J (Clin Res Ed)*. 1986;293(6543):373-375.
22. Briend A, Rowland MG, Wojtyniak B. Measures of nutritional status. *Lancet*. 1987;1(8541):1098-1099.
23. Briend A, Wojtyniak B, Rowland MG. Arm circumference and other factors in children at high risk of death in rural Bangladesh. *Lancet*. 1987;2(8561):725-728.
24. Chen LC, Chowdhury A, Huffman SL. Anthropometric assessment of energy-protein malnutrition and subsequent risk of mortality among preschool aged children. *Am J Clin Nutr*. 1980;33(8):1836-1845.
25. Samson-Fang LJ, Stevenson RD. Identification of malnutrition in children with cerebral palsy: poor performance of weight-for-height centiles. *Dev Med Child Neurol*. 2000;42(3):162-168.
26. Kong CK, Wong HS. Weight-for-height values and limb anthropometric composition of tube-fed children with quadriplegic cerebral palsy. *Pediatrics*. 2005;116(6):e839-e845.
27. Chumlea WC, Guo SS, Steinbaugh ML. Prediction of stature from knee height for black and white adults and children with application to mobility-impaired or handicapped persons. *J Am Diet Assoc*. 1994;94(12):1385-1388, 1391; quiz 1389-1390.
28. Hibbert ME, Lanigan A, Raven J, Phelan PD. Relation of armspan to height and the prediction of lung function. *Thorax*. 1988;43(8):657-659.
29. Stevenson RD. Use of segmental measures to estimate stature in children with cerebral palsy. *Arch Pediatr Adolesc Med*. 1995;149(6):658-662.
30. Cole TJ, Flegal KM, Nicholls D, Jackson AA. Body mass index cut offs to define thinness in children and adolescents: international survey. *BMJ*. 2007;335(7612):194.
31. Golden NH, Katzman DK, Kreipe RE, et al. Eating disorders in adolescents: position paper of the Society for Adolescent Medicine. *J Adolesc Health*. 2003;33(6):496-503.
32. Rosen DS; American Academy of Pediatrics Committee on Adolescence. Identification and management of eating disorders in children and adolescents. *Pediatrics*. 2010;126(6):1240-1253.
33. Golden NH, Yang W, Jacobson MS, Robinson TN, Shaw GM. Expected body weight in adolescents: comparison between weight-for-stature and BMI methods. *Pediatrics*. 2012;130(6):e1607-e1613.
34. Ivanovic DM, Leiva BP, Perez HT, et al. Long-term effects of severe undernutrition during the first year of life on brain development and learning in Chilean high-school graduates. *Nutrition*. 2000;16(11-12):1056-1063.
35. Ivanovic DM, Leiva BP, Pérez HT, et al. Head size and intelligence, learning, nutritional status and brain development. *Neuropsychologia*. 2004;42(8):1118-1131.
36. Hamill PV, Drizd TA, Johnson CL, Reed RB, Roche AF. NCHS growth curves for children birth-18 years. United States. *Vital Health Stat 11*. 1977(165):i-iv, 1-74.
37. WHO Multicentre Growth Reference Study Group. WHO Child Growth Standards based on length/height, weight and age. *Acta Paediatr Suppl*. 2006;450:76-85.
38. Grummer-Strawn LM, Reinold C, Krebs N. Use of World Health Organization and CDC growth charts for children aged 0–59 months in the United States. *MMWR Recomm Rep*. 2010;59(RR-9):1-15.
39. Ergo A, Gwatkin DR, Shekar M. What difference do the new WHO child growth standards make for the prevalence and socioeconomic distribution of undernutrition? *Food Nutr Bull*. 2009;30(1):3-15.
40. Saha KK, Frongillo EA, Alam DS, Arifeen SE, Persson LA, Rasmussen KM. Use of the new World Health Organization child growth standards to describe longitudinal growth of breastfed rural Bangladeshi infants and young children. *Food Nutr Bull*. 2009;30(2):137-144.
41. Vesel L, Bahl R, Martines J, Penny M, Bhandari N, Kirkwood BR; WHO Immunization-linked Vitamin A Study Group. Use of new World Health Organization child growth standards to assess how infant malnutrition relates to breastfeeding and mortality. *Bull World Health Organ*. 2010;88(1):39-48.
42. Wang X, Hojer B, Guo S, Luo S, Zhou W, Wang Y. Stunting and 'overweight' in the WHO Child Growth Standards—malnutrition among children in a poor area of China. *Public Health Nutr*. 2009;12(11):1991-1998.
43. Seal A, Kerac M. Operational implications of using 2006 World Health Organization growth standards in nutrition programmes: secondary data analysis. *BMJ*. 2007;334(7596):733.
44. Engle WA. Age terminology during the perinatal period. *Pediatrics*. 2004;114(5):1362-1364.
45. de Onis M, Wijnhoven TM, Onyango AW. Worldwide practices in child growth monitoring. *J Pediatr*. 2004;144(4):461-465.
46. Skuse DH, Gill D, Reilly S, Wolke D, Lynch MA. Failure to thrive and the risk of child abuse: a prospective population survey. *J Med Screen*. 1995;2(3):145-149.
47. Schwartz ID. Failure to thrive: an old nemesis in the new millennium. *Pediatr Rev*. 2000;21(8):257-264; quiz 264.

48. Kerr MA, Black MM, Krishnakumar A. Failure-to-thrive, maltreatment and the behavior and development of 6-year-old children from low-income, urban families: a cumulative risk model. *Child Abuse Negl*. 2000;24(5):587-598.
49. Atalay A, McCord M. Characteristics of failure to thrive in a referral population: implications for treatment. *Clin Pediatr (Phila)*. 2012;51(3): 219-225.
50. Growth retardation indicators in children under 5 years old. *Epidemiol Bull*. 1998;19(1):13-16.
51. Olsen EM, Petersen J, Skovgaard AM, Weile B, Jørgensen T, Wright CM. Failure to thrive: the prevalence and concurrence of anthropometric criteria in a general infant population. *Arch Dis Child*. 2007;92(2):109-114.
52. Mei Z, Grummer-Strawn LM, Thompson D, Dietz WH. Shifts in percentiles of growth during early childhood: analysis of longitudinal data from the California Child Health and Development Study. *Pediatrics*. 2004;113(6):e617-e627.
53. O'Brien LM, Heycock EG, Hanna M, Jones PW, Cox JL. Postnatal depression and faltering growth: a community study. *Pediatrics*. 2004;113(5):1242-1247.
54. Sices L, Wilson-Costello D, Minich N, Friedman H, Hack M. Postdischarge growth failure among extremely low birth weight infants: correlates and consequences. *Paediatr Child Health*. 2007;12(1):22-28.
55. Neal EG, Chaffe HM, Edwards N, Lawson MS, Schwartz RH, Cross JH. Growth of children on classical and medium-chain triglyceride ketogenic diets. *Pediatrics*. 2008;122(2):e334-e340.
56. Eskedal LT, Hagemo PS, Seem E, et al. Impaired weight gain predicts risk of late death after surgery for congenital heart defects. *Arch Dis Child*. 2008;93(6):495-501.
57. Baer MT, Harris AB. Pediatric nutrition assessment: identifying children at risk. *J Am Diet Assoc*. Oct 1997;97(10)(suppl 2):S107-S115.
58. Joosten KF, Zwart H, Hop WC, Hulst JM. National malnutrition screening days in hospitalised children in the Netherlands. *Arch Dis Child*. 2010;95(2):141-145.
59. Hulst J, Joosten K, Zimmermann L, et al. Malnutrition in critically ill children: from admission to 6 months after discharge. *Clin Nutr*. 2004;23(2):223-232.
60. Barton JS, Hindmarsh PC, Scrimgeour CM, Rennie MJ, Preece MA. Energy expenditure in congenital heart disease. *Arch Dis Child*. 1994;70(1):5-9.
61. Forchielli ML, McColl R, Walker WA, Lo C. Children with congenital heart disease: a nutrition challenge. *Nutr Rev*. 1994;52(10):348-353.
62. Schwarz SM, Gewitz MH, See CC, et al. Enteral nutrition in infants with congenital heart disease and growth failure. *Pediatrics*. 1990;86(3): 368-373.
63. Kelleher DK, Laussen P, Teixeira-Pinto A, Duggan C. Growth and correlates of nutritional status among infants with hypoplastic left heart syndrome (HLHS) after stage 1 Norwood procedure. *Nutrition*. 2006;22(3):237-244.
64. Hildreth MA, Herndon DN, Desai MH, Duke MA. Reassessing caloric requirements in pediatric burn patients. *J Burn Care Rehabil*. 1988;9(6):616-618.
65. Przkora R, Barrow RE, Jeschke MG, et al. Body composition changes with time in pediatric burn patients. *J Trauma*. 2006;60(5):968-971; discussion 971.
66. Merritt RJ, Suskind RM. Nutritional survey of hospitalized pediatric patients. *Am J Clin Nutr*. 1979;32(6):1320-1325.
67. Pollack MM, Wiley JS, Kanter R, Holbrook PR. Malnutrition in critically ill infants and children. *JPEN J Parenter Enteral Nutr*. 1982;6(1):20-24.
68. Jensen GL. Inflammation as the key interface of the medical and nutrition universes: a provocative examination of the future of clinical nutrition and medicine. *JPEN J Parenter Enteral Nutr*. 2006;30(5):453-463.
69. Soeters PB, Schols AM. Advances in understanding and assessing malnutrition. *Curr Opin Clin Nutr Metab Care*. 2009;12(5):487-494.
70. Hill AA, Plank LD, Finn PJ, et al. Massive nitrogen loss in critical surgical illness: effect on cardiac mass and function. *Ann Surg*. 1997;226(2): 191-197.
71. Zoico E, Roubenoff R. The role of cytokines in regulating protein metabolism and muscle function. *Nutr Rev*. 2002;60(2):39-51.
72. White JV, Guenter P, Jensen G, Malone A, Schofield M; Academy of Nutrition and Dietetics Malnutrition Work Group; A.S.P.E.N. Malnutrition Task Force; A.S.P.E.N. Board of Directors. Consensus statement of the Academy of Nutrition and Dietetics/American Society for Parenteral and Enteral Nutrition: characteristics recommended for the identification and documentation of adult malnutrition (undernutrition). *J Acad Nutr Diet*. 2012;112(5):730-738.
73. Siegel SA, Shealy DJ, Nakada MT, et al. The mouse/human chimeric monoclonal antibody cA2 neutralizes TNF in vitro and protects transgenic mice from cachexia and TNF lethality in vivo. *Cytokine*. 1995;7(1):15-25.
74. Ladner KJ, Caligiuri MA, Guttridge DC. Tumor necrosis factor-regulated biphasic activation of NF–kappa B is required for cytokine-induced loss of skeletal muscle gene products. *J Biol Chem*. 2003;278(4):2294-2303.
75. Mårtensson K, Chrysis D, Sävendahl L. Interleukin-1beta and TNF-alpha act in synergy to inhibit longitudinal growth in fetal rat metatarsal bones. *J Bone Miner Res*. 2004;19(11):1805-1812.
76. Franchimont D, Roland S, Gustot T, et al. Impact of infliximab on serum leptin levels in patients with Crohn's disease. *J Clin Endocrinol Metab*. 2005;90(6):3510-3516.
77. Vespasiani Gentilucci U, Caviglia R, Picardi A, et al. Infliximab reverses growth hormone resistance associated with inflammatory bowel disease. *Aliment Pharmacol Ther*. 2005;21(9):1063-1071.
78. Shamir R, Phillip M, Levine A. Growth retardation in pediatric Crohn's disease: pathogenesis and interventions. *Inflamm Bowel Dis*. 2007;13(5): 620-628.
79. Delgado AF, Okay TS, Leone C, Nichols B, Del Negro GM, Vaz FA. Hospital malnutrition and inflammatory response in critically ill children and adolescents admitted to a tertiary intensive care unit. *Clinics (Sao Paulo)*. 2008;63(3):357-362.
80. McWhirter JP, Pennington CR. Incidence and recognition of malnutrition in hospital. *BMJ*. 1994;308(6934):945-948.
81. Rogers EJ, Gilbertson HR, Heine RG, Henning R. Barriers to adequate nutrition in critically ill children. *Nutrition*. 2003;19(10):865-868.
82. Mehta NM, McAleer D, Hamilton S, et al. Challenges to optimal enteral nutrition in a multidisciplinary pediatric intensive care unit. *JPEN J Parenter Enteral Nutr*. 2010;34(1):38-45.
83. Sermet-Gaudelus I, Poisson-Salomon AS, Colomb V, et al. Simple pediatric nutritional risk score to identify children at risk of malnutrition. *Am J Clin Nutr*. 2000;72(1):64-70.
84. Coats KG, Morgan SL, Bartolucci AA, Weinsier RL. Hospital-associated malnutrition: a reevaluation 12 years later. *J Am Diet Assoc*. 1993;93(1):27-33.
85. Hulst JM, Zwart H, Hop WC, Joosten KF. Dutch national survey to test the STRONGkids nutritional risk screening tool in hospitalized children. *Clin Nutr*. 2010;29(1):106-111.
86. Rocha GA, Rocha EJ, Martins CV. The effects of hospitalization on the nutritional status of children. *J Pediatr (Rio J)*. 2006;82(1):70-74.
87. Campanozzi A, Russo M, Catucci A, et al. Hospital-acquired malnutrition in children with mild clinical conditions. *Nutrition*. 2009;25(5):540-547.
88. Humphreys J, de la Maza P, Hirsch S, Barrera G, Gattas V, Bunout D. Muscle strength as a predictor of loss of functional status in hospitalized patients. *Nutrition*. 2002;18(7-8):616-620.
89. Alvares-da-Silva MR, Reverbel da Silveira T. Comparison between handgrip strength, subjective global assessment, and prognostic nutritional index in assessing malnutrition and predicting clinical outcome in cirrhotic outpatients. *Nutrition*. 2005;21(2):113-117.
90. Marrodán Serrano MD, Romero Collazos JF, Moreno Romero S, et al. Handgrip strength in children and teenagers aged from 6 to 18 years: reference values and relationship with size and body composition [in Spanish]. *An Pediatr (Barc)*. 2009;70(4):340-348.
91. Bin CM, Flores C, Alvares-da-Silva MR, Francesconi CF. Comparison between handgrip strength, subjective global assessment, anthropometry, and biochemical markers in assessing nutritional status of patients with Crohn's disease in clinical remission. *Dig Dis Sci*. 2010;55(1):137-144.

92. Cunningham-Rundles S, McNeeley DF, Moon A. Mechanisms of nutrient modulation of the immune response. *J Allergy Clin Immunol*. 2005;115(6):1119-1128; quiz 1129.
93. Calder PC, Krauss-Etschmann S, de Jong EC, et al. Early nutrition and immunity—progress and perspectives. *Br J Nutr*. 2006;96(4): 774-790.
94. Sachdev H, Gera T, Nestel P. Effect of iron supplementation on mental and motor development in children: systematic review of randomised controlled trials. *Public Health Nutr*. 2005;8(2):117-132.
95. Johnston FE, Low SM, de Baessa Y, MacVean RB. Interaction of nutritional and socioeconomic status as determinants of cognitive development in disadvantaged urban Guatemalan children. *Am J Phys Anthropol*. 1987;73(4):501-506.
96. Georgieff MK. Nutrition and the developing brain: nutrient priorities and measurement. *Am J Clin Nutr*. 2007;85(2):614S-620S.
97. Czeizel AE, Dudas I. Prevention of the first occurrence of neural-tube defects by periconceptional vitamin supplementation. *N Engl J Med*. 1992;327(26):1832-1835.
98. Fattal-Valevski A, Azouri-Fattal I, Greenstein YJ, Guindy M, Blau A, Zelnik N. Delayed language development due to infantile thiamine deficiency. *Dev Med Child Neurol*. 2009;51(8):629-634.
99. Drotar D, Sturm L. Prediction of intellectual development in young children with early histories of nonorganic failure-to-thrive. *J Pediatr Psychol*. 1988;13(2):281-296.
100. Black MM, Dubowitz H, Krishnakumar A, Starr RH Jr. Early intervention and recovery among children with failure to thrive: follow-up at age 8. *Pediatrics*. 2007;120(1):59-69.
101. Corbett SS, Drewett RF. To what extent is failure to thrive in infancy associated with poorer cognitive development? A review and meta-analysis. *J Child Psychol Psychiatry*. 2004;45(3):641-654.
102. Galler JR, Ramsey F, Solimano G, Lowell WE, Mason E. The influence of early malnutrition on subsequent behavioral development, I: degree of impairment in intellectual performance. *J Am Acad Child Psychiatry*. 1983;22(1):8-15.
103. Liotto N, Miozzo M, Giannì ML, et al. Early nutrition: the role of genetics and epigenetics [in Italian]. *Pediatr Med Chir*. 2009;31(2):65-71.
104. Salvatore D, Buzzetti R, Baldo E, et al. An overview of international literature from cystic fibrosis registries 2: neonatal screening and nutrition/ growth. *J Cyst Fibros*. 2010;9(2):75-83.
105. Lucidi V, Alghisi F, Raia V, et al. Growth assessment of paediatric patients with CF comparing different auxologic indicators: a multicentre Italian study. *J Pediatr Gastroenterol Nutr*. 2009;49(3):335-342.
106. Hirche TO, Hirche H, Jungblut S, Stern M, Wagner TO, Wiedemann B; German CFQA Group. Statistical limitations of percent ideal body weight as measure for nutritional failure in patients with cystic fibrosis. *J Cyst Fibros*. 2009;8(4):238-244.
107. Shet A, Mehta S, Rajagopalan N, et al. Anemia and growth failure among HIV-infected children in India: a retrospective analysis. *BMC Pediatr*. 2009;9:37.
108. Manary MJ, Sandige HL. Management of acute moderate and severe childhood malnutrition. *BMJ*. 2008;337:a2180.
109. Akinbami FO, Hamzat TH, Orimadegun AE, et al. Body mass composition: a predictor of admission outcomes among hospitalized Nigerian under 5 children. *Asia Pac J Clin Nutr*. 2010;19(3):295-300.
110. Bejon P, Mohammed S, Mwangi I, et al. Fraction of all hospital admissions and deaths attributable to malnutrition among children in rural Kenya. *Am J Clin Nutr*. 2008;88(6):1626-1631.
111. Van den Broeck J, Eeckels R, Massa G. Validity of single-weight measurements to predict current malnutrition and mortality in children. *J Nutr*. 1996;126(1):113-120.
112. Mezoff A, Gamm L, Konek S, Beal KG, Hitch D. Validation of a nutritional screen in children with respiratory syncytial virus admitted to an intensive care complex. *Pediatrics*. 1996;97(4):543-546.
113. Mahdavi AM, Safaiyan A, Ostadrahimi A. Subjective vs objective nutritional assessment study in children: a cross-sectional study in the northwest of Iran. *Nutr Res*. 2009;29(4):269-274.
114. Oztürk Y, Büyükgebiz B, Arslan N, Ellidokuz H. Effects of hospital stay on nutritional anthropometric data in Turkish children. *J Trop Pediatr*. 2003;49(3):189-190.
115. Sikorski C, Kerac M, Fikremariam M, Seal A. Preliminary evaluation of the Moyo chart—a novel, low-cost, weight-for-height slide chart for the improved assessment of nutritional status in children. *Trans R Soc Trop Med Hyg*. 2010;104(11):743-745.
116. Alasfoor D, Mohammed AJ. Implications of the use of the new WHO growth charts on the interpretation of malnutrition and obesity in infants and young children in Oman. *East Mediterr Health J*. 2009;15(4):890-898.
117. Isanaka S, Villamor E, Shepherd S, Grais RF. Assessing the impact of the introduction of the World Health Organization growth standards and weight-for-height *z*-score criterion on the response to treatment of severe acute malnutrition in children: secondary data analysis. *Pediatrics*. 2009;123(1):e54-e59.
118. Yang H, de Onis M. Algorithms for converting estimates of child malnutrition based on the NCHS reference into estimates based on the WHO Child Growth Standards. *BMC Pediatr*. 2008;8:19.
119. Nuruddin R, Lim MK, Hadden WC, Azam I. Comparison of estimates of under-nutrition for pre-school rural Pakistani children based on the WHO standard and the National Center for Health Statistics (NCHS) reference. *Public Health Nutr*. 2009;12(5):716-722.
120. Nash A, Corey M, Sherwood K, Secker D, Saab J, O'Connor DL. Growth assessment in infants and toddlers using three different reference charts. *J Pediatr Gastroenterol Nutr*. 2005;40(3):283-288.
121. Gorstein J, Sullivan K, Yip R, et al. Issues in the assessment of nutritional status using anthropometry. *Bull World Health Organ*. 1994;72(2): 273-283.
122. Dylewski ML, Prelack K, Weber JM, et al. Malnutrition among pediatric burn patients: a consequence of delayed admissions. *Burns*. 2010;36(8): 1185-1189.
123. Fischbach M, Dheu C, Seuge L, Orfanos N. Hemodialysis and nutritional status in children: malnutrition and cachexia. *J Ren Nutr*. 2009;19(1):91-94.
124. Galati PC, Resende CM, Salomão RG, Scridelli CA, Tone LG, Monteiro JP. Accurate determination of energy needs in children and adolescents with cancer. *Nutr Cancer*. 2011;63(2):306-313.
125. Srivaths PR, Silverstein DM, Leung J, Krishnamurthy R, Goldstein SL. Malnutrition-inflammation-coronary calcification in pediatric patients receiving chronic hemodialysis. *Hemodial Int*. 2010;14(3):263-269.
126. Walters TD, Griffiths AM. Mechanisms of growth impairment in pediatric Crohn's disease. *Nat Rev Gastroenterol Hepatol*. 2009;6(9):513-523.
127. Mak RH, Cheung W, Cone RD, Marks DL. Orexigenic and anorexigenic mechanisms in the control of nutrition in chronic kidney disease. *Pediatr Nephrol*. 2005;20(3):427-431.
128. Listernick R. Accurate feeding history key to failure to thrive. *Pediatr Ann*. 2004;33(3):161-166.
129. Goulet O. Growth faltering: setting the scene. *Eur J Clin Nutr*. 2010;64(suppl 1):S2-S4.
130. Dodge JA, Turck D. Cystic fibrosis: nutritional consequences and management. *Best Pract Res Clin Gastroenterol*. 2006;20(3):531-546.
131. Gahagan S. Failure to thrive: a consequence of undernutrition. *Pediatr Rev*. 2006;27(1):e1-e11.
132. Viteri FE. INCAP studies of energy, amino acids, and protein. *Food Nutr Bull*. 2010;31(1):42-53.