Commentary: Measuring nutritional status of children

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Leg length has been suggested as a proxy for nutritional and environmental exposures in childhood given the associations observed in some Western populations.1,2 Sanjay Kinra et al.3 present a careful assessment of this hypothesis in an Indian population in this issue of the International Journal of Epidemiology and observe no association between nutritional supplementation and relative leg length, and relative lower leg length, among adolescents in the Hyderabad cohort. Although intriguing, given previous findings4,5 and the proposed sensitivity of ‘lower’ leg length as a marker for nutritional status,6 the null finding reported by Kinra and colleagues is in accord with other studies in non-Western populations.7,8

To our knowledge, only one other study has specifically examined the association of nutritional supplementation in early childhood with leg length in ‘childhood’.4 This study set in 1930s Britain investigated the effects of a year-long nutritional supplementation programme on change in components of height after 1 year. The children in the Hyderabad study, in contrast, had the potential to receive the supplementation for about 6 years. Another difference is that the children in the British study were about 9 years old at follow-up whereas the Indian study focused on 13–18 year olds. Importantly, whereas the supplements were directly given to the children or their families in the British study, the intervention in the Hyderabad trial was at the village level: a child was considered to be in the treatment group if s/he resided in a village where the supplementation programme was being implemented. Kinra et al.3 treat their study as a quasi-experimental cluster trial and use the Intention-to-Treat (ITT) principle in their analysis. This approach is a standard practice but, by discarding data from eligible children because of missing baseline data,9 the investigators did not entirely adhere to principles of ITT. The study might have been strengthened by clarifying whether statistical methods recommended specifically to handle missing data (individual and cluster) for ITT in cluster randomized trials were applied.10

Examining studies of nutritional supplementation and leg length, in general, it is notable that the results do not unequivocally underscore the salience of leg versus trunk length in capturing growth during childhood and early adolescence. For instance, a British study of energy intake at the age of 4 years and leg and trunk lengths at the age of 43 years,5 found that per capita family expenditure on food per week was positively associated with leg length, whereas per capita daily calorie and protein intakes were not. Additionally, per capita food expenditure per week and per capita daily calorie intake were positively associated with trunk length among boys whereas per capita daily calorie and protein intakes were associated with trunk length among girls. Based on these rather equivocal findings, the study authors speculated that leg growth may be more sensitive to socio-economic circumstances and diet than trunk growth in early childhood (<5 years) and trunk growth may be more sensitive after the age of 5 years. At the present time, therefore, it is not clear if relative leg length can be considered a valid proxy for childhood nutrition despite its potential advantage for retrospective assessment of nutritional status in early childhood or as an improvement over indirect nutritional assessment by absolute leg length.

Multiplicity of childhood nutritional measures

A number of alternative anthropometric, body compositional and biochemical methods are available for ascertaining nutritional status in children (Table 1).
Depending on the setting and the objective (individual clinical impression vs population nutritional assessment), these methods may have important advantages and disadvantages that we briefly consider.

The principal criteria for assessing growth and nutritional status in children are indices based on anthropometric measurements for stature (height or length) and body weight.\(^\text{11}\) In order to compare anthropometric data across children of different ages, population-based reference data are used including the US Centers for Disease Control,\(^\text{12}\) British growth references\(^\text{13}\) and World Health Organization child growth standards.\(^\text{14}\) Differences in a child’s height or weight from the median of the reference population can be calculated in terms of the standard deviation (z-score) above or below the median.\(^\text{15}\)

In low- and middle-income countries, child undernutrition remains prevalent,\(^\text{16}\) and a z-score of below negative two (i.e. less than \(-2\) SD) is used to indicate underweight (low weight-for-age), stunting (low height-for-age) or wasting (low weight-for-height).\(^\text{11}\) These indices are important in monitoring nutritional status as each captures different underlying biological processes.\(^\text{17}\) Weight-for-age is a general index composed of weight-for-height and height-for-age,\(^\text{18}\) which are used to identify wasting and stunting in populations.\(^\text{19}\) Used alone, however, weight-for-age may underestimate the proportion of children who are undernourished, as some undernourishment may only be detected through weight-for-height and/or height-for-age.\(^\text{20}\) In young children, weight-for-height is independent of child age and can identify both ‘thinness’ and ‘overweight’, but it is less useful in older children and adolescents where the relationship between weight and height depends on age.\(^\text{21}\)

Another important consideration is that wasting may be the result of acute starvation and/or disease, and low weight-for-age also does not differentiate chronic thinness from recent onset, whereas stunting indicates long-term nutritional inadequacies.\(^\text{11}\)

Among older children and adolescents, body mass index can be used and cut-off values have been identified to categorize thinness\(^\text{22}\) and overweight/obesity\(^\text{23}\) in children. Body mass index-for-age may also be used in children and z-scores can be calculated from the reference distributions.\(^\text{12–14}\) Other anthropometric indices such as the mid-upper arm circumference may be appropriate for use in emergency or crisis situations where collection of age, weight and height data are problematic. The advantage being that undernutrition can be quickly identified in children aged 1–5 years with an arm circumference <12.5 cm.\(^\text{24}\) Head circumference is less practical in assessing nutritional status at the population level, because only very small circumference may have sufficient specificity to indicate severe undernutrition in infants. Head circumference, however, can be used as a screening tool for child developmental or neurological disorders in clinical settings.

It is possible that adolescent or adult leg length and relative leg length may turn out to be useful as indicators of prior nutritional status in childhood in low- and middle-income countries. However, as Kinra and colleagues point out, there is currently a lack of evidence to support the usefulness of leg length and relative leg length for this purpose.

In populations where overweight and obesity are prevalent, measures of body composition can be used to quantify body fat. For example, skinfold measurement is a relatively simple and fairly accurate method of predicting body composition and has been used in large surveys.\(^\text{25}\) Skinfold measurements, however, may be of limited use in children due to large inter-observer variability and lack of available reference data.\(^\text{11,26}\) Dual X-ray absorptiometry (DXA) and magnetic resonance imaging (MRI) have improved accuracy in quantifying body composition but come at a higher cost and with limited availability.\(^\text{27}\)

Anthropometric measurements such as waist circumference have been proposed as simpler alternatives with comparable accuracy in measuring adiposity in children.\(^\text{28}\) Bioelectrical impedance analysis (BIA) is a relatively inexpensive technique that is used to estimate body fat by assessing conductivity in the fat-free body mass.\(^\text{24}\) Although BIA has only moderate accuracy in individuals, it may be suitable for population studies and in children as reference data become available.

Biochemical methods are increasingly useful to support assessment of nutritional status based on anthropometry and body composition and in epidemiological studies.\(^\text{29}\) Individuals may have underlying nutritional deficiencies although their body measurements are within normal limits.\(^\text{24}\) Many biochemical tests to measure micronutrient adequacy are available.\(^\text{30}\) In nutrition surveys or population-based studies, several technologies that require small amounts of blood have been used successfully including haematological analysis to estimate iron, folate and vitamin B12.\(^\text{24,29}\) Deficiency of vitamin A in children is a large global health problem,\(^\text{19}\) and both traditional laboratory methods and dry blood spots are available for use in population-based studies of vitamin A.\(^\text{11}\) On the other hand, zinc deficiency in children is also widespread, but the quantification of zinc intake through biochemical methods is not feasible in large surveys; therefore, population assessment of zinc deficiency is done largely on the basis of stunting prevalence.\(^\text{19}\)

**Concluding remarks**

The multiplicity of childhood nutrition measures that we attempted to summarize highlight the importance of selecting a measure based on the research question being addressed. Although each of these measures might be useful, the underlying phenomenon and
<table>
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<tr>
<th>Index or method</th>
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<th>Purpose</th>
<th>Advantages</th>
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<tr>
<td><strong>Anthropometric</strong></td>
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<tr>
<td>Weight-for-age</td>
<td>Body mass relative to age; continuous measure (z-score, based on reference population of same age and sex), underweight (−2 SD) and severely underweight (−3 SD)</td>
<td>Primarily used to identify growth faltering, acute infectious disease and poor nutritional intake</td>
<td>Simple, feasible to collect in community nutrition surveys; particularly useful for serial measurements, screening and in children &lt;1 year</td>
<td>Does not distinguish between acute and chronic forms of undernutrition; composite of height and weight of child; difficult to interpret</td>
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<td>Length/height-for-age</td>
<td>Measured length/stature (height), continuous measurement (z-score, based on reference population of same age and sex), stunted (−2 SD) and severely stunted (−3 SD)</td>
<td>Identify longitudinal growth and nutritional status; cumulative undernutrition</td>
<td>Relatively simple, feasible to collect in community nutrition surveys; measure of past and long-term nutritional status and/or adverse environment; useful for serial measurements</td>
<td>Less sensitive to marginally inadequate or short-term nutritional insufficiency; cannot differentiate between past and continuing chronic nutritional deficiencies</td>
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<tr>
<td>Weight-for-height</td>
<td>Body weight relative to height; continuous measure (z-score, based on reference population of same height and sex), wasted (−2 SD) and severely wasted (−3 SD)</td>
<td>Identify low weight-for-height or ‘thinness’; excess weight relative to height can be determined</td>
<td>Indicator of present nutritional status; can be used when age is unknown or unreliable; can quantify undernutrition along with overweight and obesity in children</td>
<td>Not a substitute for weight-for-age or height-for-age; unsuitable for use in adolescents; not able to determine if low weight-for-height is from recent or chronic undernutrition</td>
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<tr>
<td>Body mass index/body mass index-for-age</td>
<td>Weight divided by height squared; continuous measure (z-score, based on reference population of same age and sex), categories of thinness, overweight, using international cut-offs</td>
<td>Measure of body size, can be used to assess over- and undernutrition in children and adolescents</td>
<td>Can be used to quantify the degree of under- or over-nutrition, monitor and evaluate changes in nutrition over time; useful in older children and adolescents; cut-offs for overweight and underweight in children using BMI</td>
<td>BMI does not distinguish between lean mass and fat mass; BMI-for-age may be more useful for younger children</td>
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<tr>
<td>Leg length, relative leg length</td>
<td>Leg length calculated as difference between standing height and trunk length; ratio of leg length to total height or leg length to trunk length can be calculated; leg length-for-age (z-scores) can be calculated</td>
<td>Assessment of lower body growth; potential proxy for overall length or stature</td>
<td>Relative leg length in adults potentially a marker for nutritional status and environmental exposures in childhood; potential indirect assessment of stunting</td>
<td>May be prone to measurement error; limited reference data available; usefulness in screening for current child nutrition not clear</td>
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<td>Mid-upper arm circumference</td>
<td>Circumference at midpoint of the upper arm; circumference &lt;12.5 cm suggested as a proxy for low weight-for-height</td>
<td>Used in field screening of undernutrition in children aged &lt;5 years</td>
<td>Portable method does not require measurement of height or weight; can be used in emergency situations; cut-off values of 12.5 or 13.0 predictive of mortality</td>
<td>May be age/sex dependent; measurement error; possible overestimation of undernutrition in younger children, underestimation in older ones; use of z-scores recommended</td>
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<td>Head circumference</td>
<td>Occipital–frontal circumference; ratio of chest circumference to head circumference &lt;1 may suggest undernutrition</td>
<td>Used mainly in clinical settings to screen for child developmental or neurological disorders</td>
<td>May be used to assess severe undernutrition in infants &lt;6 months; typically used to screen for congenital/genetic disorders</td>
<td>Head circumference and head/chest ratio not used for initial assessment of nutritional status; does not offer clear benefits over height-for-age</td>
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### Body compositional

<p>| Skinfold thickness           | Thickness of subcutaneous tissue is measured with precision callipers at several sites on the body (e.g. triceps, subscapular) | Used to assess body composition; total body fat; and obesity            | Equations derive total body fat from skinfolds measured at several sites; relatively simple method; can be used in community nutrition surveys                                                                 | Limited for assessing undernutrition in children; single site may not represent whole body fat; limited reference data; measurement error |
| BIA                          | Small electrical current passed through the body to determine fat-free mass | Used to calculate body composition and percentage of body fat           | Safe, relatively inexpensive and portable; measurement of body fat improved with data on height, weight, age and gender; can be used in community nutrition surveys                                                                 | Precision can be affected by hydration, recent meals, physical activity; may need validation in child or multi-ethnic populations |
| DXA                          | A body scan is done by X-rays at different energies; absorption different for bone and fat tissue | Designed for measurement of bone mineral density; can be used to assess body composition; adiposity; vitamin D deficiency | Useful measure of fat distribution; can be used in children; accessible in major hospitals                                                                                                                  | Cannot differentiate intra-abdominal and subcutaneous fat; cannot be used in population-based surveys; accuracy may depend on age, adiposity |
| MRI                          | Estimates volume of lean and adipose tissue | Used primarily in research settings to image abdominal fat distribution | Estimates regional body composition, only approach to estimate intra-abdominal adipose tissue                                                                                                                                                                           | High-cost equipment, limited availability; less suitable for population-based studies; waist circumference may be a useful proxy |
| Ultrasound                   | Uses high-frequency sound waves to pass through adipose tissue until reaching muscle | Can be used to measure subcutaneous fat                                 | Safe; not expensive; estimates adipose tissue thickness; may be superior to skinfolds in obese persons                                                                                                                                                           | Validation studies may be required among subjects with varying levels of body fatness                   |</p>
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<td><strong>Biochemical</strong></td>
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<td>Serum retinol&lt;sup&gt;31&lt;/sup&gt;</td>
<td>Distribution of serum (plasma) retinol; concentration &lt;0.70 μmol/l used to indicate deficiency in children</td>
<td>Assess for vitamin A deficiency</td>
<td>Accurate measurement through HPLC; measurement of RBP as a surrogate marker only requires dried blood spot collection</td>
<td>HPLC is expensive; requires skilled personnel, blood collection, storage and transport, limiting use in large surveys; RBP may be more appropriate for large surveys</td>
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<td>Haemoglobin count&lt;sup&gt;29&lt;/sup&gt;</td>
<td>Blood test; continuous measure of haemoglobin (Hb) WHO thresholds based on Hb level (e.g. &lt;6.8 mmol/l in children) are used to define anaemia</td>
<td>Assess iron, B&lt;sub&gt;12&lt;/sub&gt; and folate deficiency; anaemia</td>
<td>Simple blood test; results immediately; cost-effective to measure anaemia prevalence in community nutrition surveys</td>
<td>Serum iron or serum ferritin testing may be required to measure iron levels</td>
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<td>Urinary iodine&lt;sup&gt;24,30&lt;/sup&gt;</td>
<td>Continuous measure of urinary iodine (μmol/l); concentration can be categorized to represent deficiency (e.g. severe &lt;0.16, moderate 0.16–0.39 and mild 0.40–0.78 in μmol/l)</td>
<td>Assess iodine deficiency; congenital hypothyroidism</td>
<td>Simple methods using urinary iodine can be employed in community nutrition surveys or epidemiological studies; fairly precise; 24-h or timed urine collection not required</td>
<td>More precise methods of measuring iodine are expensive and require 24-h collection; less feasible in field conditions</td>
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<td>Serum zinc&lt;sup&gt;36&lt;/sup&gt;</td>
<td>Determine concentration of zinc in serum or plasma through atomic absorption spectroscopy</td>
<td>Assess zinc deficiency, poor wound healing, suppressed immunocompetence</td>
<td>Direct assessment of serum zinc concentration; indirect indicators such as stunting prevalence may be used</td>
<td>Biochemical tests unreliable; zinc concentrations affected by age, gender, fasting status, etc.</td>
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<tr>
<td>Serum B&lt;sub&gt;12&lt;/sub&gt;&lt;sup&gt;37&lt;/sup&gt;</td>
<td>Techniques for measuring B&lt;sub&gt;12&lt;/sub&gt; vary, generally below 148 pmol/l is considered deficient</td>
<td>Assess B&lt;sub&gt;12&lt;/sub&gt; deficiency; peripheral neuropathy; anaemia</td>
<td>Quantifying vitamin B deficiencies is important in monitoring maternal and child health; newer measures more sensitive to detecting low B&lt;sub&gt;12&lt;/sub&gt;</td>
<td>Accurate measurement of B&lt;sub&gt;12&lt;/sub&gt; is complex; no current gold standard; not well-suited for community nutrition surveys</td>
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HPLC: high-performance liquid chromatography; RBP: retinol binding protein.
context being studied should dictate which measure is chosen. Studies such as the one by Kinra and colleagues shed light on the importance of testing whether measures used in one context are applicable in another. Continued efforts to promote the standardization and interpretation of these methods will not only help improve assessments of nutritional status but ultimately to inform policies to benefit the health and nutrition of individuals and populations.

Conflict of interest: None declared.

KEY MESSAGE

- The multiplicity of childhood nutrition measures highlight the importance of selecting a measure based on the research question being addressed. Although each of these measures might be useful, the underlying motivation (individual clinical impression vs population nutritional assessment) and context should dictate which measure is chosen.

References


