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MEASURING CHANGE IN NUTRITIONAL STATUS: A COMPARISON OF DIFFERENT ANTHROPOMETRIC INDICES AND THE SAMPLE SIZES REQUIRED

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The usefulness of different anthropometric indices to detect nutritional changes at the community level, ie, in a number of children considered as a group, was compared by using data from a longitudinal study from rural Bangladesh which followed up quarterly an average of 413 children aged 6–35 months from December 1984 to December 1987. Weight change, mid-upper arm circumference and weight-for-height responded most quickly to seasonal variations of the food situation. Height-for-age was more responsive to long-term variations. Although similar conclusions were reached when proportions of children below a cut-off point or mean indices were compared, the comparison of mean indices required a smaller sample size to detect changes. The difference in sample size needed ranged from 48 to 61 per cent. All indices varied significantly with age, which suggests that precise knowledge of age is essential for proper interpretation of nutritional surveillance data.

Nutritional status is a major determinant of child health and survival (Kielmann & McCord, 1978; Chen, Chowdhury & Huffman, 1980; Briend, Wojtyniak & Rowland, 1987) and it is important to be able to follow its evolution over time not only in individual children, but also at the community level, ie, in a number of children considered as a group. For the latter purpose, a standard procedure has been advocated (WHO, 1983), but the relative usefulness of the different approaches recommended has not yet been critically examined.

For more than 10 years, the recommended method for assessing the nutritional status of the community was to estimate the proportion of children falling below different percentage levels of the median of the growth standard (Jelliffe, 1966). Recently, it has been advised to estimate the proportion of children falling below 2 standard deviations or a given percentile of the reference population, the assumption being that this approach is less influenced by the age structure of the sample being surveyed (Waterlow *et al.*, 1977). It is not known, however, to what extent this more complicated approach improved our ability to detect nutritional changes.

Comparing the means of nutritional indices, instead of counting observations falling under arbitrary cut-off points, allows the use of a wider range of statistical tests (WHO Working Group, 1986), but this approach is not widely used.

Indicators responding to nutritional changes over the short term and the long term may not be the same (Bairagi, 1987) and weight change may be more useful

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than other indices to measure rapid changes of the nutritional status (Waterlow, 1981; Brown, Black & Becker, 1982; WHO Working Group, 1986; Bairagi, 1987).

Finally, for most populations, little information is available on the amount of nutritional change one has to expect in a community and also on the standard deviations of some nutritional indices. This knowledge is required to estimate the sample sizes needed to detect nutritional changes.

The resulting picture is rather confusing and health workers wanting to set up a nutritional surveillance system in a community face difficult choices regarding the type of indicators to use, the way to analyse their data and the estimation of the sample size required.

The present analysis aims at clarifying some of these issues. It is based on data collected during a study in rural Bangladesh (Aziz *et al.*, 1989). The community studied was affected by seasonal food shortages but there is some evidence that over the 3 years of follow-up, the general nutritional situation slightly improved. The usefulness of different indices to measure change of nutritional status is assessed here by examining their variations over time. Sample sizes needed for different approaches to the detection of similar changes in the future are also estimated.

Materials and methods

This analysis is based on data collected for the evaluation of a water and sanitation project, the Mirzapur Handpump Project, which has been described in detail elsewhere (Aziz *et al.*, 1989). To evaluate the impact of the project on the health and nutrition of children, two areas, separated by a distance of about 5 km were studied: an intervention area with approximately 5000 inhabitants and a control area with a population of 4600 inhabitants. Handpumps, latrines and hygiene education were provided only to the intervention area. For the present analysis data from the two areas were combined.

In this area, rainfall occurs mainly between June and August. The main crops are rice and jute. Rice, the staple food, is harvested three times a year, with the major harvest taking place in April to June. Availability of food at the household level varies considerably according to seasons, from place to place and from year to year, and also in relation to socio-economic status. For the poor families, however, there is usually a critical period at the end of the monsoon up to the November harvest, coinciding with a low demand for labour.

In January 1984 a census of the study area was completed to collect baseline socio-demographic data and to compile a demographic data base. This data base was updated at monthly intervals until the end of the study period in December 1987 with the recording of all births, deaths, change of marital status and migration.

Measurements of heights and weights were made on average every 3 months from October 1984 to December 1987: in December-January, March-April, June-July and September-October. An attempt was made to have regular rounds but the interval between them ranged from 2 to 4 months, with a mean of 87 d.

Measurements were made on all children less than 3 years of age. For each round, children who had reached 6 months were added to the sample whereas those who were above 36 months were dropped. Age structure of the sample remained similar throughout the study.

Anthropometric measurements were made by trained female community health workers (CHWs) with at least 10 years of schooling. Three teams, each consisting of one CHW assisted by a porter, conducted the surveys. Nude or lightly clothed children were weighed to the nearest 0.1 kg on a Salter scale, which was regularly checked against standard weights. Recumbent length for children less than 2 years of age was measured to the nearest 0.1 cm on a locally made wooden platform with a sliding footboard. For children over 2 years a height scale was used having a stick firmly secured to a solid wooden base and equipped with a flat movable arm. Mid-upper arm circumference (MUAC) was measured by a standard technique (Jelliffe, 1966).

Anthropometric measurements were compared with the NCHS standards (Hamill *et al.*, 1979). Nutritional indices for weight-for-age, height-for-age, and weight-for-height, were calculated in percentages of the NCHS median and also in Z-scores, representing the difference between an anthropometric measurement and the NCHS reference expressed in standard deviation units (WHO, 1986). Weight change was measured by the difference in weight between two quarterly rounds adjusted using the exact number of days between two measures and expressed as average monthly weight change. For simplicity, lack of weight gain was taken as a cut-off point for some part of the analysis. Analysis in terms of standard deviations below reference standards was not done due to lack of appropriate weight gain standards.

To compare the responsiveness of different nutritional indices to change, two sets of comparisons were made. First, seasonal variations were assessed by comparing measurements made in June-July and September-October when food is scarce in the community with those of December-January and March-April. Second, nutritional status at the beginning of the study, in 1984 and 1985, was compared with the nutritional status during 1986 and 1987 to assess how different indicators change over the long term.

Analysis was made by pooling observations: data from each child aged between 6 and 35 months at the time of measurement were included in the analysis. Children who remained within the age range for several rounds were included several times. Only observations with full sets of anthropometric variables, including weight change since last visit, were included in the analysis. Observations from the first round (October 1984), with no information about weight change, were not included.

Comparisons of means were done by *t*-tests or one-way analysis of variance whenever appropriate. After analysis of variance, 2-by-2 comparisons of several means were done using Scheffé's test (Armitage, 1971). The performance of different nutritional indicators to detect changes of nutritional status between two periods of time was estimated by calculating the normalized distance d_a between different periods by the formula:

$$d_a = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{(1/2)(s_1^2 + s_2^2)}}$$

where $\bar{x}_1$ and $\bar{x}_2$ represent the means of the index for each period and s_1^2 and s_2^2 its variances (Habicht, Meyers & Brownie, 1982). Sample size needed for detecting changes of nutritional status were calculated according to Armitage (1971) and Casagrande, Pike & Smith (1978).

Results

Altogether, 5371 sets of observations were available for analysis. They covered a time span of 39 months and were collected over 13 rounds, representing an average of 413 children per round (range: 351–514). Means of all nutritional indices were lower during the lean season compared to the rest of the year with the exception of height-for-age which was significantly higher (Table 1). Comparison of normalized distances showed that weight change, MUAC and weight-for-height were the nutritional indicators which changed most between seasons. Similar results were obtained when Z-scores were used instead of percentage of the medians.

Means of height-for-age, weight-for-age and MUAC were significantly higher during the last 2 years of the project than at its beginning (Table 1). Comparison of normalized distances showed that this difference was more pronounced for height-for-age than for any other index.

Plotting the values of the different indices over time showed that height-for-age had seasonal variations which were

Table 1. *Seasonal and long-term variations of means of different nutritional indices.*

Nutritional index	*Monsoon and pre-harvest seasons n=2867 Mean*	*(s.d.)*	*Other seasons n=2504 Mean*	*(s.d.)*	$d_a.10^2$	*First 2 years n=2145 Mean*	*(s.d.)*	*Last 2 years n=3226 Mean*	*(s.d.)*	$d_a.10^2$
Weight-for-age										
% NCHS	73.5	(9.4)	74.1	(9.2)*	6.80	73.4	(9.4)	74.1	(9.2)††	8.28
Z-score	−2.51	(0.91)	−2.48	(0.90)$^{n.s.}$	3.66	−2.55	(0.92)	−2.46	(0.89)†††	8.91
Height-for-age										
%NCHS	90.8	(4.2)	90.4	(4.2)***	9.71	90.2	(4.3)	90.8	(4.1)†††	14.59
Z-score	−2.41	(1.10)	−2.53	(1.10)***	11.08	−2.58	(1.13)	−2.41	(1.08)†††	15.23
Weight-for-height										
%NCHS	87.8	(8.0)	89.1	(7.7)***	17.07	88.6	(7.7)	88.5	(7.9)$^{n.s.}$	1.46
Z-score	−1.33	(0.85)	−1.18	(0.82)***	18.08	−1.24	(0.82)	−1.26	(0.84)$^{n.s.}$	2.44
Weight change averaged per month, g	139	(188)	187	(194)***	25.12	168	(198)	162	(198)$^{n.s.}$	3.1
MUAC, mm	129	(11)	131	(11)***	19.74	129	(11)	131	(11)†††	13.6

n.s.: non-significant
$d_a.10^2$ = (normalized distance) × 100
For comparison of seasons: $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.
For comparison of short-term *vs* long term: $^{\dagger\dagger}P < 0.01$; $^{\dagger\dagger\dagger}P < 0.001$.

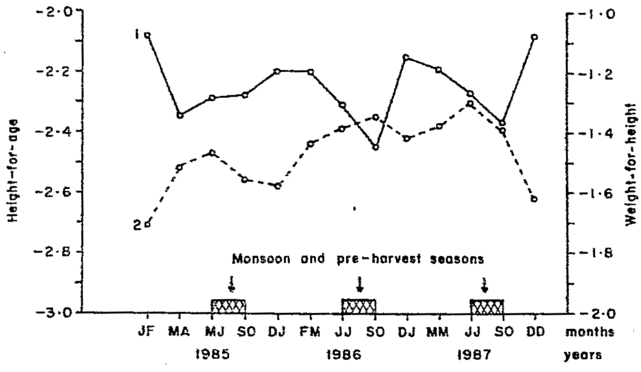

Fig. 1. *Seasonal variations of weight-for-height and height-for-age Z-scores.* 1: Weight-for-height; 2: height-for-age.

opposed to those of weight-for-height (Fig. 1). This contrasted with weight change and MUAC which had seasonal variations similar to those of weight-for-height (Fig. 2). These latter indicators were at their lowest during the monsoon and pre-harvest seasons during the second and third year of the study but not in the first year.

Cumulative frequency of weight-for-height, both for the monsoon and pre-harvest seasons are presented in Fig. 3. Cumulative frequency of height-for-age, both at the beginning and at the end of the study are presented in Fig. 4. For these two indicators, change occurs in all parts of the distribution and is not limited to the lower range: cumulative frequency curves remained separated up to the highest values of nutritional status.

Comparison of the percentages of observations below standard cut-off points lead to the same conclusions as the comparisons of mean indices, both for short-term and long-term comparisons (Table 2). Differences of percentages of children below the standard cut-off points were highly significant for weight change, MUAC and weight-for-height when comparing between seasons and for height-for-age when comparing over the years. Calculation of the sample size needed for a new study to detect differences in nutritional status comparable to those found here showed, however, that in most cases, comparisons of the percentages of children

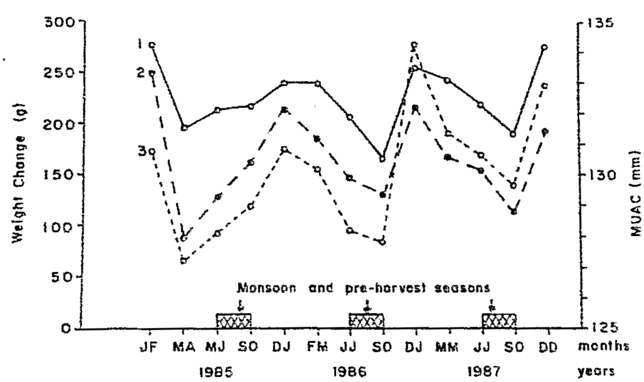

Fig. 2. *Seasonal variations of monthly weight change, MUAC and weight-for-height. Weight-for-height, expressed in Z-score, is represented with the same scale as in Fig. 1.* 1: Weight-for-height; 2: weight change; 3: MUAC.

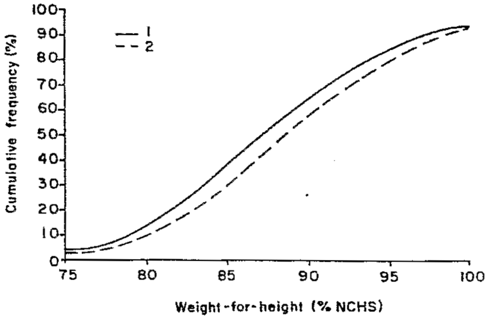

Fig. 3. *Cumulative frequency of weight-for-height at different seasons.* 1: Monsoon and pre-harvest; 2: other seasons.

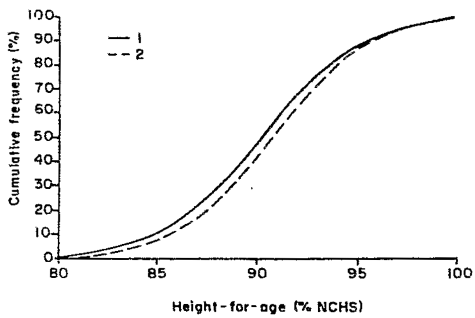

Fig. 4. *Cumulative frequency of height-for-age at the beginning and at the end of the study.* 1: First 2 years; 2: last 2 years.

Table 2. *Seasonal and long-term variations of percentages (%) of children below standard cut-off points for different nutritional indices.*

Nutritional index	*Cut-off*	*Monsoon and pre-harvest season (n=2867)*	*Other seasons (n=2504)*	*First 2 years (n=2145)*	*Last 2 years (n=3226)*
Weight-for-age					
% NCHS	80	77.3	75.8$^{n.s.}$	78.0	75.5†
Z-score	−2	73.3	72.2$^{n.s.}$	74.2	71.7†
Height-for-age					
%NCHS	90	42.8	46.6**	47.9	42.8†††
Z-score	−2	63.8	70.1***	70.1	65.2†††
Weight-for-height					
%NCHS	80	12.8	9.4***	11.7	10.5$^{n.s.}$
Z-score	−2	19.9	14.1***	16.6	16.09$^{n.s.}$
Weight change averaged per month	0	12.5	18.4***	16.7	14.2†
MUAC, mm	125	32.6	26.6***	27.5	32.3†††

n.s.: non-significant
For comparison of seasons: $^{**}P < 0.01$; $^{***}P < 0.001$.
For comparison of short-term *vs* long-term: $^{\dagger}P < 0.05$; $^{\dagger\dagger\dagger}P < 0.001$.

below standard cut-off points require a larger sample size than comparisons of means (Table 3). For short-term comparisons, using means of weight change and weight-for-height required a sample size 59 and 61 per cent smaller than the samples needed for comparisons of proportions. For long-term comparisons with height-for-age, the reduction of the sample size needed when using means was 48 per cent.

To obtain measures of nutritional status which are not influenced by variations of the age structure of the measured sample, it is preferable to choose nutritional indices which are similar in different age groups. In this study, however, all nutritional indices varied with age (Table 4). The indices of younger children, aged 6–11 months, were all significantly different from those of older children ($P < 0.05$).

Discussion

This analysis suggests that weight changes, MUAC and weight-for-height

Table 3. *Sample sizes needed to detect the same seasonal and long-term differences in nutritional status as observed in this study with a 80 per cent power at the 0.05 level of significance with different nutritional indices.*

Nutritional index	*Seasonal variations*		*Long-term variations*	
	Comparison between means	*Comparison of percentages below cut-off points*	*Comparison between means*	*Comparison of percentages below cut-off*[1]
Weight-for-age				
%NCHS	3400	—	2290	4570
Z-score	—	—	1960	5040
Height-for-age				
% NCHS	—	—	740	1530
Z-score	—	—	680	1470
Weight-for-height				
% NCHS	540	1400	—	—
Z-score	490	690	—	—
Weight change averaged per month, g	260	620	—	3360
MUAC, mm	400	940	820	1470

[1]Same cut-off points as in Table 2.
Sample sizes were calculated only for comparisons found statistically significant in Tables 1 and 2.
Sample sizes were rounded off to the nearest ten.

Table 4. *Means (and standard deviations) of nutritional indices for different age groups.*

Nutritional index	*Age groups (months)* 6–11 (n=1167)		12–23 (n=2328)		24–35 (n=1876)	
Weight-for-age						
% NCHS	77.9	(10.4)	72.5	(8.8)	73.0	(8.5)
Z-score	−1.99	(0.96)	−2.62	(0.83)	−2.66	(0.84)
Height-for-age						
% NCHS	93.4	(3.9)	90.2	(3.9)	89.4	(4.0)
Z-score	−1.75	(1.03)	−2.62	(1.03)	−2.74	(1.03)
Weight-for-height						
% NCHS	92.1	(8.9)	87.1	(7.2)	88.0	(7.8)
Z-score	−0.83	(0.90)	−1.46	(0.81)	−1.24	(0.72)
Weight change averaged per month, g	231	(210)	151	(174)	141	(194)
MUAC, mm	125	(10)	129	(10)	135	(10)

For the five variables, differences between the three age groups were highly significant ($P < 0.001$) by one-way analysis of variance.

are the best indicators to measure short-term variations of nutritional status. Weight change is easy to compute from field data and does not require the measurement of height. To detect short-term nutritional changes, weight change requires a smaller sample size than weight-for-age and even weight-for-height. Although not usually recommended for nutritional surveillance (Keller & Fillmore, 1976; WHO, 1983; Mason & Mitchell, 1983; Mason *et al.*, 1984), weight change seems to be most effective to monitor short-term nutritional changes.

In this study, weight-for-height was more useful than weight-for-age to measure short-term changes. Calculation of weight-for-height requires a precise measure of height which makes the field measurements more time-consuming.

Height-for-age is the most appropriate index to measure nutritional changes over the long term but is inadequate to measure short-term changes: in this community, height-for-age varied in opposition to other indices and was at its highest level during the time of food scarcity. A systematic measurement error on height causing variations in directions opposed to these two indicators can be ruled out since variations of weight-for-height closely followed those of MUAC and of weight change which are independent of height. A similar seasonal pattern of height-for-age variation, presumably related to the slow response of height to nutritional change, was reported in a previous study from Bangladesh (Brown *et al.*, 1982).

Weight-for-age is related both to weight-for-height and height-for-age (Waterlow, 1976; Keller & Fillmore, 1983). Because these two indices vary inversely in this community, this may explain why weight-for-age was less sensitive to changes than other indices.

MUAC reflected nutritional changes both in the short term and in the long term. Easy to use in the community, it seems well adapted to give a quick assessment of the situation. However, the differences of MUAC observed between seasons and over the long term in this study were small compared to the level of measurement errors (Zerfas, 1979). Averaging minimizes the effect of random measurement errors (Armitage, 1971) and it may be valid to compare MUAC of different groups of children provided they are measured by the same observers with the same technique. In other circumstances, when there may be a different systematic error for the different samples, as may occur between observers who do not use exactly the same technique, interpretation of surveys based on MUAC may be impossible. Also, MUAC increases with age (Table 4) and cannot be used for comparisons of nutritional status between groups of children with different age structures.

Comparison of variations of nutritional changes in the community using means of nutritional indices or percentages of children falling below standard cut-off points led to similar conclusions. Calculation of the sample size needed to detect similar changes showed, however, that in most cases, a smaller sample size is required when comparing means. Performance of these two types of comparisons depends on the type of distribution of nutritional indicators among well-nourished and malnourished children and on an adequate choice of cut-off points (Brownie & Habicht, 1984). This is rarely considered when use of proportions is recommended for monitoring nutritional change: counting children below standard cut-off points was introduced initially because this was easy to use at a time when computers and pocket calculators were not widely available (Jelliffe, 1966). This approach would still be recommended if changes of nutritional status occurred mainly at the lowest end of the distribution, but this was not observed in our sample. It may also have some value for the evaluation of targeted interventions, although in this case it may be more appropriate to limit the assessment of nutritional change to children who received help.

Because nutritional status in the first year of the study was not at its lowest during the monsoon and pre-harvest season, sample sizes needed to detect similar seasonal variations of nutritional status are likely to be slightly overestimated by this analysis. This should not affect, however, the comparison between different nutritional indicators.

Using Z-scores instead of percentages of medians did not markedly affect the response of different nutritional indices to change. All indices, including Z-scores, varied considerably with age. This also applied to weight-for-height and MUAC which are often used in surveys where age is unknown. When making comparisons between groups of children, it is therefore important to ensure that similar age structures are used or that adjustment for age is made during the analysis. Using local growth standards may be another way to minimize this problem. In situations where age is not known with precision, it may be preferable to make comparisons excluding children less than 1 year of age: in this case, the comparison is less likely to be affected by small differences of age structure. Precise knowledge of age is especially needed for assessment of long-term nutritional changes based on comparisons of height-for-age.

Although the focus of this analysis is on measures of change of nutritional status over time in one particular area, it is likely that our findings could apply to comparison of children living in different areas. They may also be useful for the design of impact studies.

In conclusion, this study suggests that adequately choosing the type of indicators according to the type of comparison to be made and using means instead of counting proportions of children falling below cut-off points may considerably reduce the workload required for nutritional surveillance of a community.

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