Alternative anthropometric indicators of mortality[1,2]

Radheshyam Bairagi, DSc, Mridul K Chowdhury, MPhil, Young J Kim, PhD, and George T Curlin, MD, MPH

ABSTRACT The ability of anthropometric indicators, weight-for-age, height-for-age, weight-for-height, weight velocity, and height velocity to discriminate mortality during a one-year period is examined for three time frames beginning in different seasons. Data on approximately 1,000 children of one to four years of age come from the Matlab, International Centre for Diarrhoeal Disease Research, Bangladesh. The indicators' mortality-discriminating power is assessed in terms of the magnitude of difference between the mean indicator values of living and dead children expressed in standard deviation units and of the maximum sum of sensitivity and specificity. The indicators' mortality curve by nutritional status shows the discriminating power visually; the *t* test indicates its statistical significance. Weight-for-age and height-for-age perform better than weight velocity and height velocity as discriminators of mortality during a one-year period. The ability of weight and height velocity to discriminate short-term mortality is examined by comparing the mean velocity of the last two bimonthly intervals of the dead children. Weight velocity is likely to be a good indicator of short-term mortality. *Am J Clin Nutr* 1985;42:296–306.

KEY WORDS Anthropometric indicators, mortality indicators, nutritional indicators, weight velocity

Introduction

Protein-energy malnutrition (PEM) is a serious problem in developing countries, where more than half the deaths to children under five are related directly or indirectly to malnutrition (1, 2). Malnutrition of individuals or of a population can be assessed clinically, biochemically, or by anthropometry. The clinical and biochemical methods require highly skilled personnel or techniques, while anthropometry can be obtained by less skilled personnel and requires only simple apparatus. Moreover, mild or moderate protein-energy deficiency in children is difficult to detect by clinical examination or by biochemical indicators but has been mainly measured in terms of anthropometry.

Many anthropometric indices are defined in the literature and are accepted as indicators of nutritional status of children (3, 4). But it is not clear which index should be preferred for a given purpose and why. The current consensus is that the ultimate value of an anthropometric index rests on its capacity to discriminate and identify individuals and populations at high risk of the functional consequences of malnutrition—mortality and morbidity (5, 6).

Mortality is the most serious consequence of malnutrition. But only four studies in the literature show the relationship between anthropometric indices and mortality for non-hospitalized populations. To demonstrate this relationship, Sommer and Lowenstein used arm circumference-for-height (7), and Kielmann and McCord used weight-for-age (8).

[1] From the Carolina Population Center, University of North Carolina at Chapel Hill (RB); International Centre for Diarrhoeal Disease Research, Dhaka, Bangladesh (MKC); Department of Population Dynamics, The Johns Hopkins University, Baltimore, MD (YJK); United States Agency for International Development, Washington, DC (GC).

[2] Address reprint requests to: Dr. Radheshyam Bairagi, Carolina Population Center, University of North Carolina at Chapel Hill, University Square 300-A, Chapel Hill, NC 27514.

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Chen et al (9) were the first to compare the validity of several cross-sectional anthropometric indices as predictors of mortality. Trowbridge and Sommer (10), Bairagi (11), and Cogill (12) discussed strengths and weaknesses of these three studies.

The fourth study on this subject was done in Kasongo, Africa (13). The mortality-predicting power of the anthropometric indices appeared to be much weaker in this study than in the previous three studies. After reviewing these four studies and other related work, Bairagi hypothesized that the mortality-discriminating power of an anthropometric indicator will be higher for a population in which food intake depends on socioeconomic status (SES) than for a population in which food intake does not depend on SES (14). Because the present work is based on only one population, this hypothesis cannot be tested here directly. However, an analogy of this hypothesis is that the discriminating power of long-term mortality of an anthropometric index which has a higher correlation with SES will be stronger than that of another anthropometric index whose correlation with SES is lower.

Weight-for-age, height-for-age, weight-for-height, weight velocity, and height velocity are the indices considered here. Among them weight-for-age and height-for-age are the better indicators of chronic malnutrition. Chronic malnutrition originates from long-term factors like SES. One of our hypotheses, therefore, is: weight-for-age and height-for-age are better than the other three indices as discriminators of long-term (here one-year) mortality. A part of this hypothesis, that weight-for-age and height-for-age are better than weight-for-height as discriminators of mortality during a one-year period, was found true in Chen et al's study (9) for children in the second year of life. But in that study no reason for the superiority of one index over the other as a mortality discriminator is given. Furthermore, Chen et al and the Kasongo study team (13) speculated that weight velocity is a better discriminator of mortality than weight-for-age, which is measured cross-sectionally. Although they did not specify the time period of that mortality, this speculation is clearly at variance to our hypothesis for discriminating mortality during a one-year period.

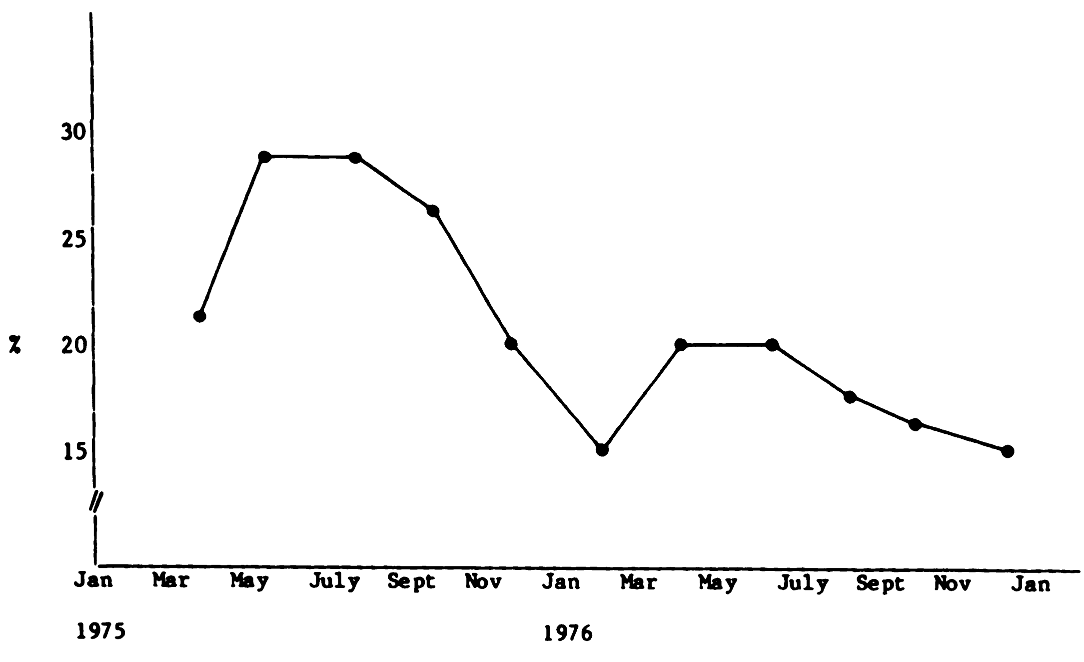

FIG 1. Percentage of severely malnourished children in different months in 1975–76.

TABLE 1
Correlation matrix of the indicators measured in August 1975 (velocity for April–August 1975), SES, and one-year mortality (dead = 0, alive = 1)*

Variables	1	2	3	4	5	6	7	8
1. Weight-for-age	1	0.80	0.67	0.28	0.12	0.20	0.13	0.12
2. Height-for-age		1	0.12	0.11	0.29	0.14	0.11	0.10
3. Weight-for-height			1	0.34	−0.12	0.17	0.08	0.10
4. Wt velocity				1	0.16	0.04	0.01	0.06
5. Ht velocity					1	0.06	0.03	0.04
SES								
6. Floor space						1	0.38	0.13
7. Mother's education							1	0.06
8. Mortality								1

* n = 958. r = 0.05 will make $p < 0.05$.

We have shown elsewhere (15) that change in nutritional status or weight velocity is more sensitive than weight-for-age to short-term effects, such as diarrhea. Our other hypothesis, therefore, is: weight velocity is a good indicator of short-term (here two-month) mortality, since acute malnutrition will be reflected more in weight velocity.

The two hypotheses mentioned above will be tested here for children one to four years of age. To clarify our understanding, the relationship of these indices with SES will be considered.

Data and methods

The data of this study came from the Matlab Field Station of the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B). Since 1963 the ICDDR,B has operated a field research program in Matlab thana, Bangladesh, involving the provision of diarrheal health services and the longitudinal registration of births, deaths, marriages, and migrations in 228 villages with a 1974 population of 263,000. Matlab and the ICDDR,B have been described in previous publications (9, 16).

In January 1975, investigators at the ICDDR,B undertook a study in 12 villages in Matlab to investigate the influence of domestic water-use patterns on diarrheal diseases and to examine the interaction between diarrhea and the nutritional status of children (17). Bimonthly weight and height measurements of children under ten years of age and the collection of weekly diarrheal data for all people were a part of the field work. Diarrheal data collection began in January 1975, but anthropometry began April 1975. Field work continued through December 1976. Data of the Chen et al (9) study came also from 83 villages of Matlab including two villages of this study. It is estimated that approximately 40 children of this study were common in Chen et al's work.

Weights of all children were taken on Salter scales to the nearest 50 g, and heights were taken on locally made measuring scales to the nearest 0.10 cm. The same scale was used for a child throughout the study. Workers received training for collecting weight and height data.

No direct estimate of measurement error of weight and height data was available. Measurement error was estimated indirectly from the following equation (18):

$$\sigma'^2 = \sigma^2 + \frac{2\sigma_\epsilon^2}{t^2}$$

where σ'^2 is the observed variance of monthly velocity (weight or height), σ^2 (unknown) is the true variance of weight velocity, σ_ϵ^2 (unknown) is the measurement error variance, and t is the time interval (in months) between measurements for calculating velocity. Putting the values of more than one σ'^2 for more than one time interval (two months, four months, and six months) from this

TABLE 2
Mean and standard deviation of the indicators in June 1975 (velocity for April–June 1975) and the corresponding d_s, MSS, and t for discriminating one-year mortality

Indicators	Alive (919) $\bar{X}$	Alive (919) SD	Dead (19) $\bar{X}$	Dead (19) SD	d_s	MSS	t
Weight-for-age	67.00	9.96	58.26	8.62	0.94	135	4.36*
Height-for-age	85.69	5.78	80.74	3.96	1.00	141	5.34*
Weight-for-height	86.00	7.08	82.79	8.77	0.40	115	1.58
Wt velocity (g/mo)	63.29	323.08	19.05	253.25	0.15	114	0.75
Ht velocity (cm/mo)	0.78	1.91	0.77	0.69	0.01	103	0.05

* $p < 0.01$.

study, made estimation of σ_t^2 possible. It was found that although the quality of weight data was very good, the quality of height data was less satisfactory.

Exact dates of birth and mortality data were available from the ICDDR,B vital registration records. For this work the information on the children who were one through four years old at the time of anthropometric measurement was considered.

In the analysis that follows, dwelling floor space is used as the indicator of family economic status. Although obviously flawed, it is arguably the best single indicator of economic status available from the 1974 Matlab Census (19). Mother's education was found to be strongly related to child mortality in the Matlab area (20), and it is used as another measure of SES in this study. Both floor space and mother's education (ME) are used in the interval scale. Number of years of formal education represents the level of ME.

Anthropometric indices were created on the basis of National Center for Health Statistics (NCHS) reference

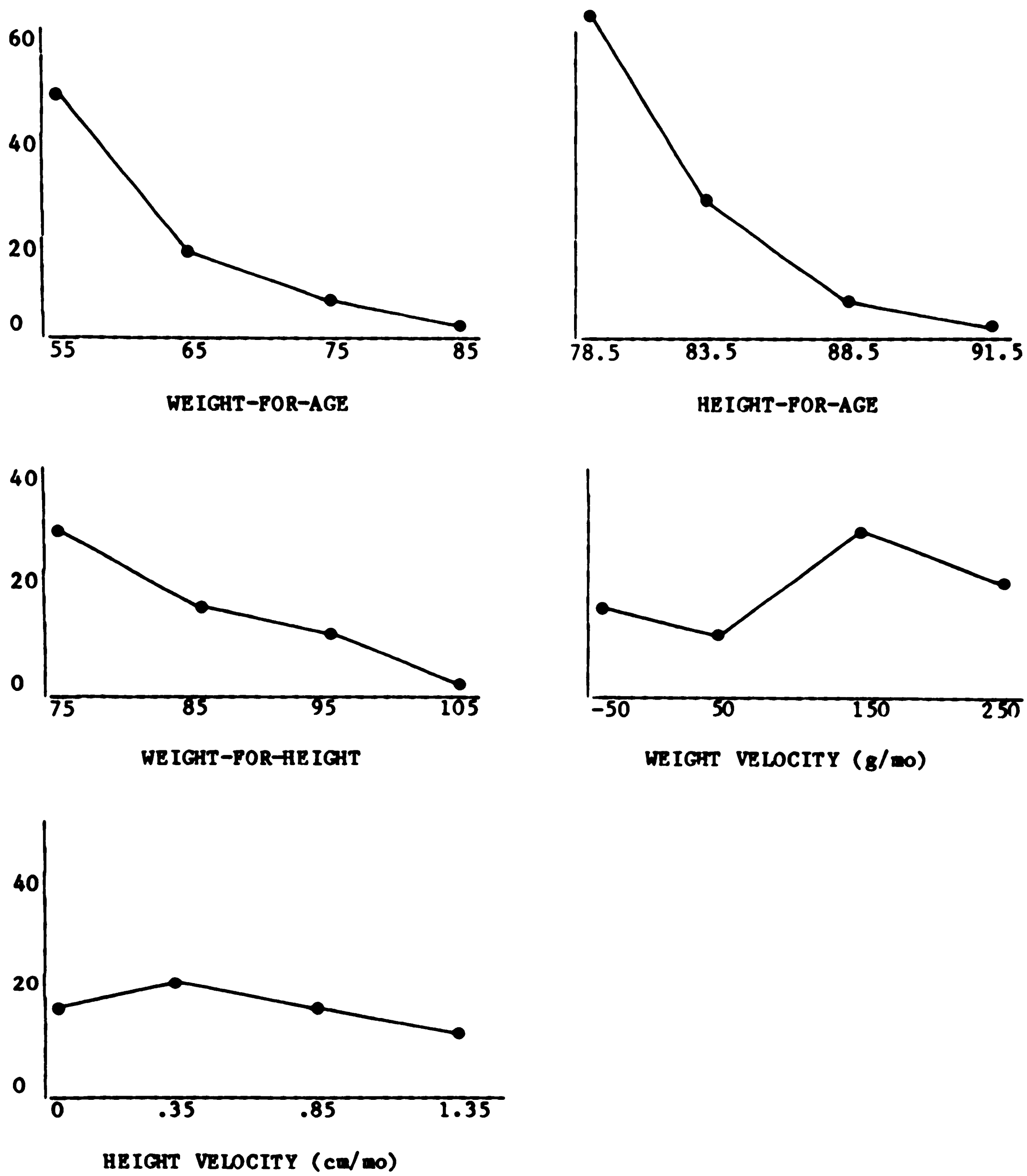

FIG 2. Mortality rate (per 1000/year) according to level of the indicators in June 1975 (Velocity: April–June).

data (4) from the software available at the ICDDR,B computer. Waterlow et al (21) recommended the use of z-scores. But Cogill (12) demonstrated that it made no important difference whether the indicators were expressed as the NCHS percentage of median or as z-scores. Percentage of median is simple to calculate, is in greater use in the literature, and therefore is used in this work.

An anthropometric index may be used for assessing, screening, surveilling, and monitoring malnutrition, and also for identifying the factors of malnutrition. An index that is good for one purpose is usually, but may not necessarily, be good for all purposes (12, 22-24). Cogill (12) compared several performance criteria for selecting the best anthropometric indicator for discriminating mortality during a one-year period and demonstrated that the normalized distance, d_a, was the best, and that the maximum sum of sensitivity and specificity (MSS) was the second best. The normalized distance is defined as

$$d_a = \frac{\bar{x}_1 - \bar{x}_2}{\left[\frac{S_1^2 + S_2^2}{2}\right]^{1/2}}$$

where

$\bar{x}_1$ = mean of the indicator of living children,
$\bar{x}_2$ = mean of the indicator of dead children,
S_1^2 = variance of the indicator of living children,
S_2^2 = variance of the indicator of dead children.

The probability of correctly diagnosing a diseased (here dead) child is called sensitivity, Se(k), and the probability of correctly classifying a disease-free (here living) child is called specificity, Sp(k). While d_a and MSS are two important summary measures used to evaluate the indicators, the discriminating power of the indicators will be more visible from the mortality curves of the indicators. All three methods, therefore, will be used.

Starting from April 1975, two-month, four-month, and six-month growth velocities were calculated. The number of deaths in any short-term period (say two months) was too small to test the second hypothesis. The combined deaths of several two-month periods could not be related to weight velocity, because weight velocity changed markedly over the study period as the result of famine and season (see **Fig 1**). Moreover, growth velocity of any two periods was likely to be correlated as a result of catch-up growth. Facing all these problems, we tried a different technique. Looking at the period from April 1975 through December 1976, we calculated the means and standard deviations of children's weight velocities as observed during the last pair of two-month intervals before death. Similar results were obtained for height velocities.

The research protocol was reviewed and approved by the human subject committee of the International Centre for Diarrhoeal Disease Research, Bangladesh.

Results

Approximately 1,000 children aged one through four years were available at each period of the study. Dwelling floor space of the families of the study children had a symmetric distribution with a mean of 235 square feet and a standard deviation of 106 square feet. Slightly more than 2% of the mothers had been educated for six years or more; 78% had no formal education.

Weight-for-age is the most widely used anthropometric index, and a child having a value on this index less than or equal to 60% of the reference median weight is usually termed as severely malnourished. To gain an idea about the dynamics and status of malnutrition in the study population, see Figure 1 for the percentage of severely malnourished children aged one through four years in different months from April 1975 through December 1976. In Bangladesh 1974-75 was a famine period. The effects of that famine and of the months November through February being the good season as the result of the harvest of the main crop (aman paddy) are clearly apparent in this figure.

Table 1 is a correlation matrix of SES, anthropometric indices, and mortality. As mentioned at the beginning, the relationship of SES variables with weight-for-age and height-for-age was stronger in terms of cor-

TABLE 3
Mean and standard deviation of the indicators in August 1975 (velocity for April-August 1975) and the corresponding d_a, MSS, and t for discriminating one-year mortality

Indicators	Alive (938)		Dead (23)		d_a	MSS	t
	$\bar{X}$	SD	$\bar{X}$	SD			
Weight-for-age	66.58	9.75	58.39	8.82	0.71	144	4.38*
Height-for-age	85.84	5.71	82.13	4.59	0.72	126	3.81*
Weight-for-height	85.27	7.62	80.00	8.52	0.65	124	2.94*
Wt velocity (g/mo)	79.74	178.39	12.35	179.16	0.38	116	1.78
Ht velocity (cm/mo)	0.68	0.73	0.50	0.44	0.30	114	1.88

* $p < 0.01$.

relation coefficients than the relationship of SES variables with the other three indices. Of course, the correlation coefficient of weight-for-height and floor space was higher than the correlation coefficient of height-for-age and floor space. Although this inversion was unexpected, we should remember that floor space was only an approximate measure of SES.

Means and standard deviations of weight-for-age, height-for-age, and weight-for-height in June 1975 and of the velocity of weight

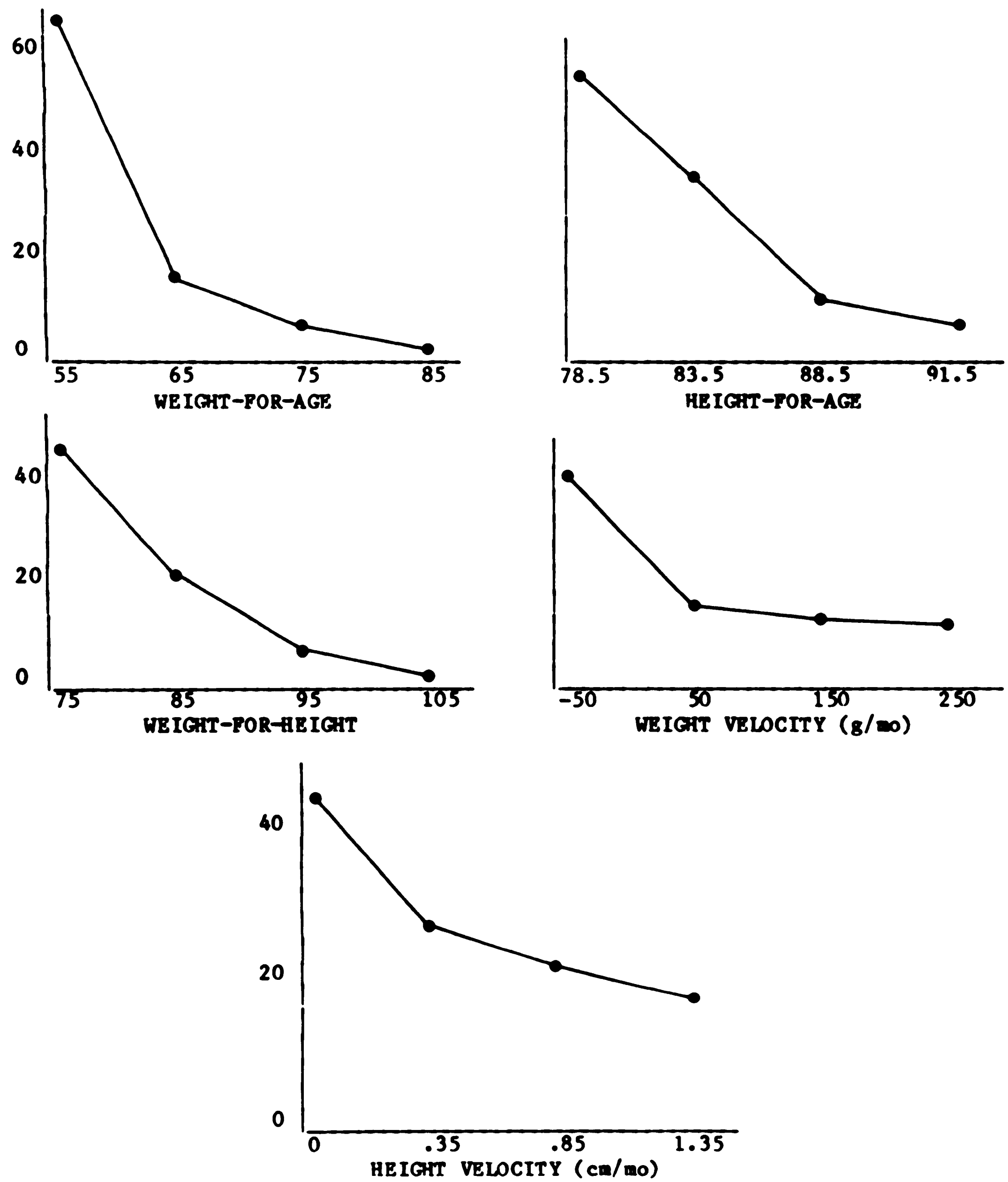

FIG 3. Mortality rate (per 1000/yr) according to level of the indicators in August 1975 (Velocity: April–August).

and of height of two months' interval (April through June 1975) of the children according to survival status during a one-year period from June 1975, and the corresponding d_a and MSS are given in **Table 2;** death rates for various levels of different indicators are given in **Figure 2.** In Table 2 and Figure 2, weight-for-age and height-for-age appear to be the best indicators of subsequent mortality during a one-year period. Weight-for-height follows them. These results are similar to those of Chen et al (9) for children in the second year of life. However, two-month velocity of weight and height both appear to be poor indicators of mortality during a one-year period.

Similar results for four-month growth velocity (April through August 1975) and for cross-sectional indicators in August 1975 appear in **Table 3** and **Figure 3;** and six-month growth velocity (April to October 1975) and cross-sectional indicators for October 1975 are given in **Table 4** and **Figure 4.** The results of Tables 3 and 4 and of Figures 3 and 4 were obtained mainly to investigate whether the growth velocity of a longer interval is a better indicator of mortality than that of a shorter interval. It appears that the mortality-discriminating power of four-month growth velocity of both weight and height is somewhat more than that of two-month velocity. For six-month intervals, the discriminating power of height velocity is improved further; but for weight velocity, it is not only poor but negative. Overall, seen by any criterion, the discriminating power of weight velocity is lower than weight-for-age, and that of height velocity is lower than height-for-age for each of the intervals.

From Tables 1–3 and Figures 2–4, a negative trend is noticed in the discriminating power of the cross-sectional indices over time. From April 1975 to October 1975, the nutritional status in the study population was improved to a large extent (see Fig 1). This trend is therefore an indication of a relationship between current nutritional status and the discriminating power of the cross-sectional indices. To get this point clear from empirical evidence, d_a of weight-for-age, height-for-age, and weight-for-height were calculated for December 1975, April 1976, August 1976, and December 1976, for subsequent mortality during a one-year period (**Table 5**). A close examination of d_a and MSS in Tables 1–5 does not provide any clear evidence for the relationship between the discriminating power of the cross-sectional indices and current nutritional status. Weight velocity and height velocity of the last two bimonthly intervals of dead children are given in **Table 6.** The average weight velocity of the last two-month interval before death was negative (−60 g/mo) and substantially lower ($p \simeq 0.10$) than that of the average velocity of the previous interval. These results suggest that weight velocity is a good indicator of short-term mortality. However, height velocity does not seem to have this property.

Discussion

A number of limitations and problems of this work deserve attention. First, the information on cause of death was not available. As a result, deaths unrelated to nutrition, such as accidental deaths, could not be excluded to refine the relationship between the indicators and mortality.

Second, the number of deaths was too

TABLE 4
Mean and standard deviation of the indicators in October 1975 (velocity for April–October 1975) and the corresponding d_a, MSS, and t for discriminating one-year mortality

Indicators	Alive (1015) $\bar{x}$	Alive (1015) SD	Dead (15) $\bar{x}$	Dead (15) SD	d_a	MSS	t
Weight-for-age	67.38	9.89	63.27	8.55	0.44	110	1.84
Height-for-age	85.71	5.49	82.67	4.30	0.62	126	2.70†
Weight-for-height	86.33	7.92	86.53	11.78	−0.02	106	−0.07
Wt velocity (g/mo)	101.46	134.92	147.13	174.83	−0.29	107	−1.01
Ht velocity (cm/mo)	0.60	0.56	0.42	0.28	0.42	118	2.48*

* $p < 0.05$.
† $p < 0.01$.

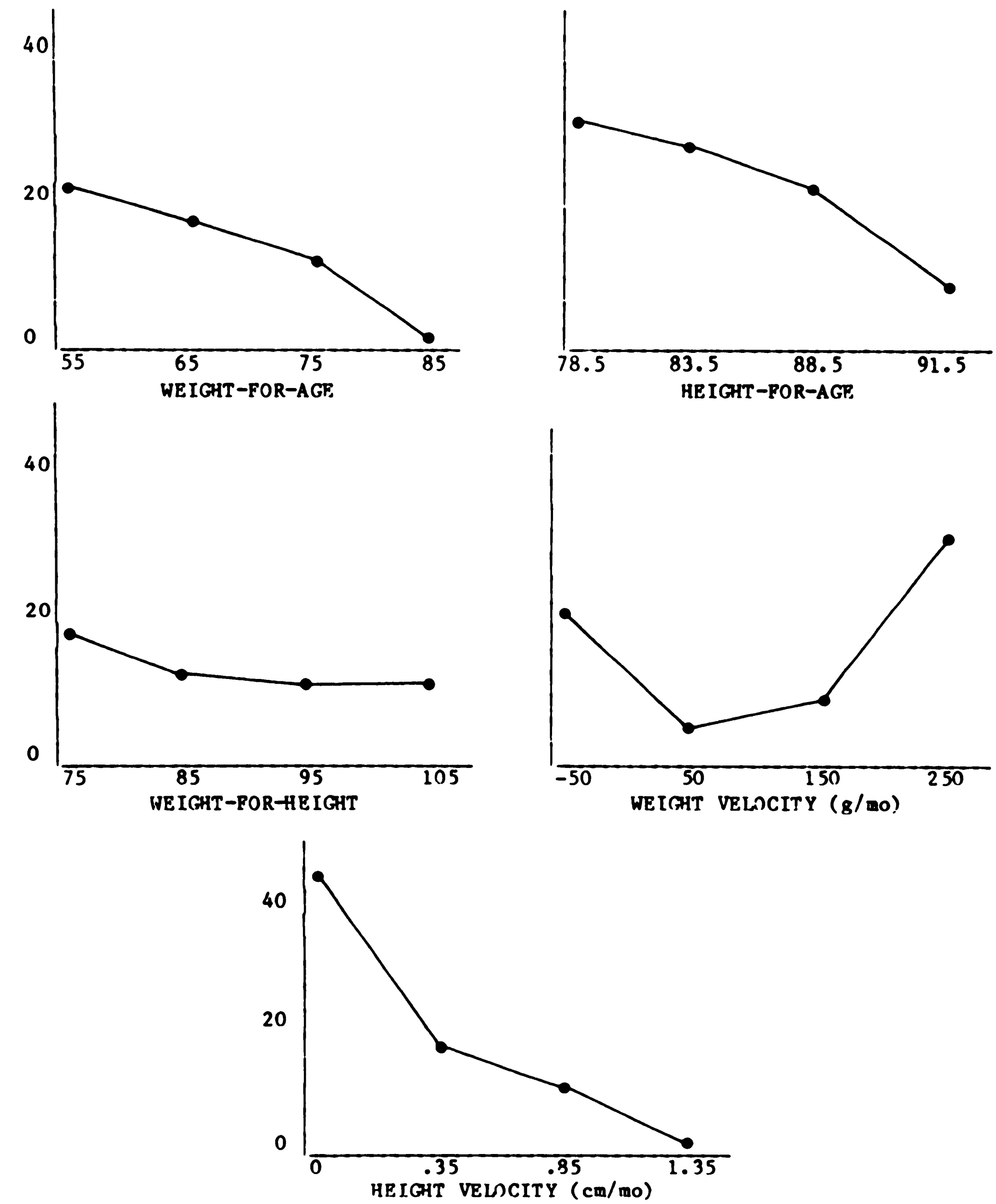

FIG 4. Mortality rate (per 1000/yr) according to level of the indicators in October 1975 (Velocity: April–October).

small to study the relationship of the indicators and mortality-controlling for age and sex, two important biological determinants of mortality, and for SES. Furthermore, the small number of deaths in combination with deaths unrelated to nutrition made the sampling error of d_a large and its fluctuation over the study period high. As a result, a clear understanding of the relationship between the current nutritional status and the mortality-discriminating power of the cross-sectional indices was not possible.

Third, although the use of NCHS reference required length data for children under two

TABLE 5
d_a of the cross-sectional indicators for discriminating one-year mortality for different time periods

Indicators	1975 December	1976 April	1976 August	1976 December
Weight-for-age	0.55	0.54	1.14	0.69
Height-for-age	0.16	0.39	0.86	1.00
Weight-for-height	0.53	0.23	1.07	0.18

years, only height data were available. Those height data were used instead of length for calculating height-for-age and weight-for-height. This might have made height-for-age and weight-for-height for children under two biased. However, relative discriminatory power of indices was not affected by this possible bias in the indices.

Fourth, poor quality of height data might have reduced the mortality-discriminating power of height-related indices to some extent. But how much reduction occurred could not be estimated.

Finally, the specific hypothesis that weight velocity is a better indicator than attained weight as a discriminator of short-term mortality could not be tested in this study.

Despite these limitations, this study is probably important in several aspects. Most importantly, this study demonstrates for the first time that the growth velocity (weight or height) even of six-months' interval is inferior to attained growth (weight or height) in identifying mortality during a one-year period. In addition to the examination of relative discriminating power of mortality of several cross-sectional and longitudinal anthropometric indices based on weight, height, and age, it attempts to find the underlying reason why one index is superior to others by correlating these indices with SES.

The U-shaped curve of mortality by weight velocity in Figure 4 was unexpected. To find a plausible explanation for this pattern, the relationship between the weight velocity and SES was further examined. It seems that as a result of sudden improvement in the overall situation including food supply, after the 1974–75 famine in Bangladesh, weight velocity during August through October 1975 and thus during April through October was accelerated. This acceleration was relatively larger for the low weight-for-age children as a result of catch-up growth. These children, in turn, were in relatively lower SES and thus had a higher risk of mortality.

Weight velocity is considered to be one of the best indicators of the health of children, and it has been in extensive use for monitoring children's health. Why did weight velocity appear inferior to attained weight (weight-for-age) as a discriminator of mortality during a one-year period?

The notion that weight velocity may be a better discriminator of mortality than the child's attained weight comes from the idea that the weight velocity is a better indicator of current nutritional status. While this is

TABLE 6
Velocity of weight (g/mo) and height (cm/mo) of the last two two-month intervals before death

Time period	Weight No	Weight $\bar{X}$	Weight SD	Height No	Height $\bar{X}$	Height SD
Last measurement taken within 2 mo prior to death	24	−60	422	14	0.38	0.44
Last measurement taken between 2–4 mo prior to death	28	102	229	14	0.35	0.61
Correlation between 2 intervals	18	−0.321			−0.114	
	t	1.665			0.060	
	p	≃0.10		12	>0.90	

generally true, whether the weight velocity should be better than attained weight as a discriminator of mortality depends on other factors. We discuss them here briefly.

Attained weight (weight-for-age) is a better indicator of chronic malnutrition than weight velocity, while weight velocity is better for measuring acute malnutrition. Chronic malnutrition results from long-term factors like low SES, whereas acute malnutrition results from short-term factors like diarrhea. Thus, attained growth may classify children not only by the degree of chronic malnutrition, but also by the factors that bring it about. Chronic malnutrition and its related factors are likely to continue for a long time, and theoretically throughout the lifetime of a child. As a result, attained weight is likely to be a good discriminator of long-term mortality. On the other hand, acute malnutrition and its related factors are likely to be short-lived. An episode of diarrhea may affect the weight velocity seriously, but not the attained weight to that great an extent. A child may die within a short period of time (a month or so) from that episode. This death is likely to be discriminated better by the weight velocity. If the child survives from that attack, his weight velocity and attained weight are likely to return soon to a position consistent with long-term factors; and his subsequent mortality risk is likely to be consistent with his attained weight, not with the temporary weight velocity that he had during or just before or after the said attack. As a result, weight velocity is not likely to be a good discriminator of long-term mortality. However, negative weight velocity shortly before death provides a strong indication that weight velocity is a good indicator of short-term mortality.

In short, this study suggests that weight-for-age and height-for-age are important and better than weight velocity and height velocity as discriminators of long-term mortality; and weight velocity is a good indicator of short-term mortality.

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