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Comparison of Weight- and Height-based Indices for Assessing the Risk of Death in Severely Malnourished Children

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To compare the effectiveness of treating malnourished children in different centers, the authors believe there is a need to have a simple method of adjusting mortality rates so that differences in the nutritional status of the children are taken into account. The authors compared different anthropometric indices based on weight and height to predict the risk of death among severely malnourished children. Anthropometric data from 1,047 children who survived were compared with those of 147 children who died during treatment in therapeutic feeding centers set up in African countries in 1993. The optimal ratio of weight to height determined by logistic regression was weight (kg)/height $(m)^{1.74}$ (95% confidence interval of β estimate 1.65–1.84). The receiver operating curves (sensitivity vs. specificity) showed that the body mass index (weight (kg)/height $(m)^2$), optimal ratio of weight to height, and weight/height index expressed as the percentage of the median of the National Center for Health Statistics' standard were equivalent and superior to the weight/height index expressed as the *z* score of the National Center for Health Statistics' standard to predict death. As the optimal ratio of weight to height is easier to calculate than the weight/height index expressed as the percentage of the median or *z* score and does not depend upon either standards or tables, the optimal ratio of weight to height could be conveniently used to adjust mortality rates for nutritional status in therapeutic feeding centers. *Am J Epidemiol* 1996;144:116–23.

anthropometry; child nutrition disorders; mortality; risk; statistics

Mortality among children treated for severe malnutrition varies considerably among different centers (1, 2) in both emergency and nonemergency settings. Variations in mortality rates can be ascribed to inherent differences in the children or differences in management. Mortality is related to the degree of malnutrition on admission (3, 4) and also to other risk factors such as the presence of dehydration (5, 6), electrolyte disturbance (3, 4), hepatic dysfunction (7), presence of specific nutritional deficiencies (8, 9), and presence and severity of associated infections (10). Differences in therapeutic feeding practices may also influence the mortality rate (11, 12). In most therapeutic feeding centers that treat severe malnutrition, it is not possible to assess electrolyte imbalance, hepatic dysfunction, or specific nutrient deficiency; the criteria for admission are therefore, of necessity, related to anthropometric criteria and simple clinical signs, such as the presence or absence of edema.

Since age is difficult to assess in developing countries, anthropometric indices based on weight and height are usually used to assess nutritional status and detect underweight subjects (13). Weight/height indices are expressed as the percentage of the median (WHP), centile, or *z* score (WHZ), which is the deviation from the median of the National Center for Health Statistics' standard (14), expressed in multiples of the standard deviation. Centile tables are inappropriate for severely malnourished children, as the values are outside the range of the tables. The World Health Organization recommends the use of the *z* score, because these scores are consistent among different age groups and because the indices are directly comparable (15).

However, the calculation of WHP or WHZ in a large number of children is cumbersome, since it requires the use of tables with anthropometric standards fol-

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Abbreviations: ORWH, optimal ratio of weight to height to assess the risk of death; ORWHc, common estimate of the optimal ratio of weight to height to assess the risk of death; WHP, weight/height index expressed as the percentage of the median of the National Center for Health Statistics' standard; WHZ, weight/height index expressed as *z* score, which is the deviation from the median of the National Center for Health Statistics' standard, expressed in multiples of the standard deviation.

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lowed by calculation. This process may be made less time consuming by the use of a computer. Yet, computers are not usually available. Moreover, computer software programs to calculate anthropometric indices were written to analyze nutritional surveys, and their use requires some computer expertise, rarely available in the field. The derivation of a simple anthropometric index that is closely related to prognosis and easily calculated in the field, with a pocket calculator, would allow more meaningful comparison among centers when mortality rates are adjusted according to the nutritional status of the children on admission. It would also be useful when making management decisions on individual children.

In this study, we have related the mortality rate in nine different centers to the standard World Health Organization criteria and also to simple ratios of weight to powers of height, in particular, to body mass index (weight (kg)/height $(m)^2$) to determine how they relate to the risk of death. We examined whether these simple ratios of weight to powers of height could be used to adjust the observed mortality rates for differences in the anthropometric state of groups of children admitted to different centers.

MATERIALS AND METHODS

Patients

The study was carried out in nine therapeutic feeding centers set up by nongovernmental organizations for the treatment of severely malnourished children during emergency relief operations in 1993. The centers were in Sierra Leone (one center), Rwanda (three centers), and Madagascar (five centers). In Rwanda and Sierra Leone, children were from a displaced population fleeing civil unrest. In Madagascar, they were from a famine-prone area.

The admission criteria used in all the centers were 1) the weight/height index of <70 percent of the median, 2) the presence of edema in both feet, or 3) a mid-upper arm circumference of <110 mm. The centers were set up in makeshift facilities and provided treatment for severely malnourished children as recommended in emergency relief operations (16). This treatment was based on feeding a diet based on a mixture of dried skim milk, oil, and sugar. Medical treatment was given when necessary. Children were considered cured 2 weeks after they reached a weight/height index of >80 percent of the median and achieved dissipation of edema.

Data on weight, height, and edema were recorded for all children on the day of admission. Weight was measured to the nearest 100 g. Recumbent length (for children below 85 cm) or standing height (for those above 85 cm) was measured to the nearest millimeter. Edema was assessed by applying pressure for 3 seconds to both feet. Age was obtained from mothers' interviews. Anthropometric data, taken during routine measurement, were recorded from patients' charts. WHZ and WHP were calculated using a nutritional anthropometry program (17).

Analysis of children lost to follow-up

The group of children whose outcome was unknown because of early discharge from the centers was compared at admission with the others. Comparison of the proportion of children with edema was performed with the chi-square test, and comparison of anthropometric characteristics was performed with the Mann-Whitney nonparametric test (18).

Optimal power of height in the determination of the weight/height ratio for assessing death risk

To determine the optimal power of height to use in the ratio of weight to height (ORWH) for assessing the risk of death, a logistic regression (19) was carried out. Logarithms of weight and height were entered into the model as independent variables, with death as the dependent variable. To take into account the possible differences in the mortality rate among centers caused by variations of either child characteristics, other than weight or height, or differences in management, we introduced eight dummy variables (one if the child was present in the corresponding center, zero otherwise) in the logistic model as independent variables. Coefficients of the logarithms of weight and height in each logistic regression were used to estimate the mean and 95 percent confidence interval of the ORWH (see the Appendix) (20). This model was first fitted separately for children with and without edema. Second, a unique logistic model was fitted to the whole sample using the same independent variables plus an additional dummy variable for the presence of edema (one if yes, zero otherwise). The fit of this unique model was compared through the likelihood ratio test (21) with the fit of a global model with logarithms of weight and height, center, and edema as independent variables but assuming different coefficients for the logarithms of weight and height and for the center in the presence of edema or not. (This corresponds to a logistic model with the independent variables cited above and the interactions between those variables and edema.) The likelihood of this global model is strictly the product of the likelihoods of the two logistic models that were fitted separately to the data of children with, and to the data of those without, edema. Finally, a possible correction of the mortality prediction was tested by means of the likelihood ratio test, with age group (6–12, 13–24, 25–36, 37–59 months of age) and dependence of the coefficients of the logarithms of weight and height and of edema to the center and age group by using the corresponding interaction terms in the logistic model.

Comparison of groups

Age and the usual anthropometric indices were compared between children who survived and children who died by analyses of variance after adjustment for center, separately for children with and without edema (22). The same analyses were performed on anthropometric indices calculated as the ratio of weight to powers of height. Normality of the distribution of each index was assessed within this experimental design by the Shapiro-Wilk criterion (23). Logarithmic transformation of each index was necessary to guarantee the gaussian distribution. The logarithmic transformation of WHZ was performed on WHZ + 9, which provides the best fit for the gaussian distribution.

Construction and comparison of receiver operating curves

By using a logistic regression model with an anthropometric index (logarithm of body mass index, ORWH, WHP, and WHZ + 9) as independent variable and center indicator for children with or without edema, we calculated the sensitivity and specificity of each anthropometric index for different cut-off points (24). For this purpose, children were put into either a high risk or a low risk category, depending on their nutritional status relative to an arbitrarily chosen cut-off point, and the number of children who died or who survived during treatment in each category was determined. The ability of anthropometric indices, including ORWH, to differentiate between children who died and those who survived was assessed by plotting receiver operating curves (sensitivity vs. 1 − specificity) (25). These curves are drawn for each index by systematically varying the value of the cut-off point. The distance between the receiver operating curve and the diagonal is a measure of the discriminating ability of an indicator.

The receiver operating curve obtained for each index was characterized by its index of detectability (da), which corresponds to the mean difference between index means of the dead and surviving samples, taking into account the variability of the indices within each sample (26). Since the distributions of the indices after logarithmic transformation are gaussian in the dead and surviving populations, and if the receiver operating curves are parallel when expressed on gaussian probability scales, the comparison of the index of detectability can be performed by the z-da statistic (26), which follows approximately the distribution of a standardized gaussian deviate. This statistic takes into account the correlation of different indices measured on the same children.

Calculation and logistic regressions were performed with Biomedical Data Processing (27), Statistical Product for Service Solution (28), and Statistical Analysis System (29) software programs.

RESULTS

Altogether, data on 1,441 children aged 6–59 months were available. Among these children, 1,047 were discharged from the centers after recovery and 147 died.

The outcome was unknown for 247 children who left the centers before complete recovery and were considered as defaulters. These children were excluded from the analysis. The group of children lost during treatment was not different from the group of children followed up to discharge or death for age, with a mean of 30 months (standard deviation, 17 months) versus a mean of 30 months (standard deviation, 16 months), or presence of edema, with a mean of 38 percent versus a mean of 32 percent. However, the mean WHZ and WHP were lower in defaulter children than in the others: for WHZ, a mean of −2.83 (standard deviation, 1.04) versus −2.63 (standard deviation, 0.98) ($p < 0.01$); and for WHP, a mean of 73.7 (standard deviation, 9.5) versus 75.3 (standard deviation, 9.2) ($p < 0.02$).

Mortality rates, as well as the proportion of children with edema, and the means for age, WHZ, and WHP varied among the different centers (table 1).

The ORWH to predict death, taking into account the differences among centers regarding efficacy, is presented in table 2 for children with edema and for those without edema. The common estimate (ORWHc) was 1.74 (95 percent confidence interval 1.65–1.84). No difference could be demonstrated between the model with a common estimate and the model with separate estimates (chi-square = 10.228, 10 df, $p > 0.6$). Edema itself was a significant risk factor for death (odd ratio = 3.8, 95 percent confidence interval 2.2–6.6). On the contrary, no effect of age group was observed ($p > 0.56$), and no evidence of variation in the parameters of the common model with center or age group (interaction terms) could be demonstrated ($p > 0.18$ and $p > 0.43$, respectively).

Comparison of the characteristic distributions between the group of children who died and those who survived is presented in table 3. The mean values for WHZ, WHP, body mass index, ORWHc, and age were

TABLE 1. Characteristics of followed children by therapeutic feeding center in Africa, 1993

	No. of children	Mean age (months)	% of deaths	% of edematous children	Mean WHZ*	Mean WHP*
Sierra Leone	244	32 (17)†	14	57	−2.85 (0.98)	73.1 (9.3)
Madagascar 1	131	23 (17)	4	1	−2.52 (0.83)	75.8 (7.3)
Madagascar 2	75	26 (14)	0	3	−2.46 (0.73)	77.1 (6.3)
Madagascar 3	106	27 (14)	0	17	−2.14 (1.05)	80.1 (10.0)
Madagascar 4	114	26 (15)	4	2	−2.96 (0.57)	72.3 (5.1)
Madagascar 5	199	30 (16)	6	9	−2.93 (0.68)	72.5 (6.1)
Rwanda 1	98	36 (16)	37	64	−2.45 (1.17)	77.2 (11.6)
Rwanda 2	115	40 (14)	10	77	−2.05 (1.13)	81.2 (10.6)
Rwanda 3	112	30 (17)	42	50	−2.75 (1.11)	74.3 (10.4)

* WHZ, weight/height index expressed as z score, which is the deviation from the median of the National Center for Health Statistics' standard, expressed in multiples of the standard deviation; WHP, weight/ height index expressed as the percentage of the median of the National Center for Health Statistics' standard.
† Numbers in parentheses, standard deviation.

TABLE 2. Results of the logistic regression analysis determining the optimal power of height in the ratio of weight to height to assess the risk of death among some severely malnourished African children, 1993

	Mean coefficients		Logarithm (likelihood)	Optimal power of height	
	Logarithm of weight (kg)	Logarithm of height (cm)		Mean	95% CI*
Children with edema (n = 388)	9.18 ± 1.56†	−15.85 ± 3.34	−135.179	1.727	1.41–2.04
Children without edema (n = 806)	10.82 ± 1.82	−19.24 ± 3.65	−164.882	1.778	1.60–1.96

* CI, confidence interval.
† Standard error.

significantly higher in children with edema than in children without edema. The mean values for WHZ, WHP, body mass index, and ORWHc were significantly lower in children who died than in children who survived for children both with and without edema.

Receiver operating curves are plotted in figure 1 for ORWHc, body mass index, WHP, and WHZ separately in children with edema and in children without edema. There was a different pattern for each anthropometric index for high specificity values (more than 80 percent) between children with and those without edema. The deviation from the gaussian distribution of each nontransformed anthropometric index between dead and surviving children after adjustment for center was significant for each variable ($p < 0.0001$). After logarithmic transformation, there were no significant differences ($p > 0.5$), allowing us to compare receiver operating curves. Moreover, the receiver operating curves, when expressed on gaussian probability scales, were almost perfectly parallel (figure 2). Table 4 shows the da differences and the z-da statistical significance of the comparison between the different anthropometric indices in children with and without edema. There was no significant difference between indicators when applied to children with edema. For children without edema, ORWHc, body mass index, and WHP were not significantly different from each other, but they were each better than WHZ to differentiate between children who died and children who survived.

DISCUSSION

This study was carried out to explore whether simple combinations of weight and height are efficiently related to prognosis and thus could be used to adjust the risk of death among children attending therapeutic feeding centers.

Among the data recorded, 247 children were not included in the study because of uncertainty about outcome. Sudden departures are common in feeding centers and difficult to avoid. The mean WHZ and WHP values, on admission, were lower for children who left than for the remainder. It is thus possible that the mothers of children who left became discouraged because of failure to improve rapidly. This may have led to underestimation of the proportion of children who died in our study. This selection bias is unlikely to change our estimate of ORWHc substantially because, to modify the estimate, the relation between

TABLE 3. Age and anthropometric characteristics of the subjects in relation to mortality, Africa, 1993

	Age (months)	WHZ*	WHP*	BMI*	Weight (kg)/ height (m)$^{1.74}$ ratio
			Children with edema		
Survived (n = 319)	40 (14)†	−2.01 (1.06)	81.7 (10.0)	13.39 (1.55)	12.93 (1.56)
Died (n = 69)	38 (13)	−2.86 (0.81)	73.7 (7.4)	12.24 (1.23)	11.71 (1.15)
Mean adjusted difference‡	2.29 ± 1.86§	0.98 ± 0.14‖	9.2 ± 1.3‖	1.36 ± 0.20‖	1.41 ± 0.20‖
			Children without edema		
Survived (n = 728)	26 (16)	−2.79 (0.81)	73.7 (7.4)	12.29 (1.25)	11.46 (1.16)
Died (n = 78)	22 (16)	−3.51 (0.77)	65.9 (6.6)	10.98 (1.16)	10.10 (1.06)
Mean adjusted difference	3.27 ± 2.10	0.40 ± 0.10‖	4.5 ± 0.9‖	0.78 ± 0.15‖	0.84 ± 0.05‖

* WHZ, weight/height index expressed as z score, which is the deviation from the median of the National Center for Health Statistics' standard, expressed in multiples of the standard deviation; WHP, weight/ height index expressed as the percentage of the median of the National Center for Health Statistics' standard; BMI, body mass index (weight (kg)/height (m)^2).

† Numbers in parentheses, standard deviation.

‡ Adjusted on therapeutic feeding center indicators through analysis of variance.

§ Standard error.

‖ $p < 0.001$, adjusted comparison between the two groups (died, survived) after logarithmic transformation for WHZ, WHP, BMI, and weight/height$^{1.74}$ ratio.

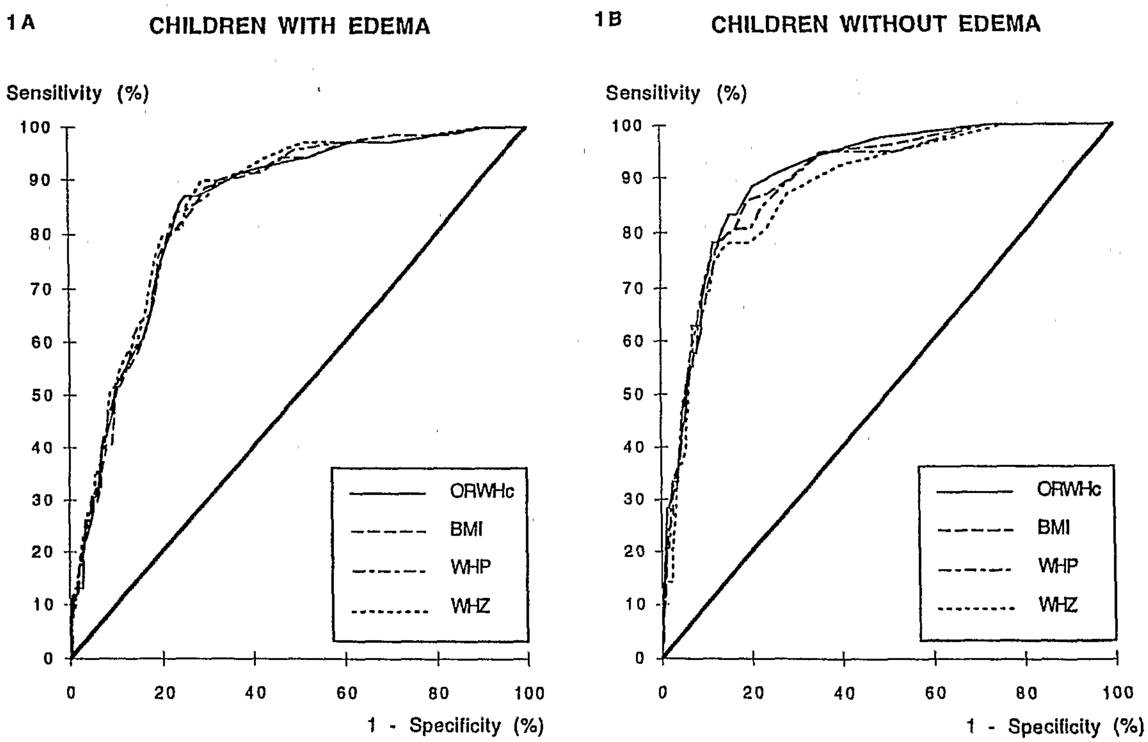

FIGURE 1. Receiver operating curves for different anthropometric indices, in children with edema (A) and without edema (B) in Africa, 1993. ORWHc, common estimate of the optimal ratio of weight to height to assess the risk of death (weight (kg)/height (m)$^{1.74}$); BMI, body mass index (weight (kg)/height (m)^2); WHP, weight/height index expressed as the percentage of the median of the National Center for Health Statistics' standard (percentage of the reference median); WHZ, weight/height index expressed as z score, which is the deviation from the median of the National Center for Health Statistics' standard, expressed in multiples of the standard deviation.

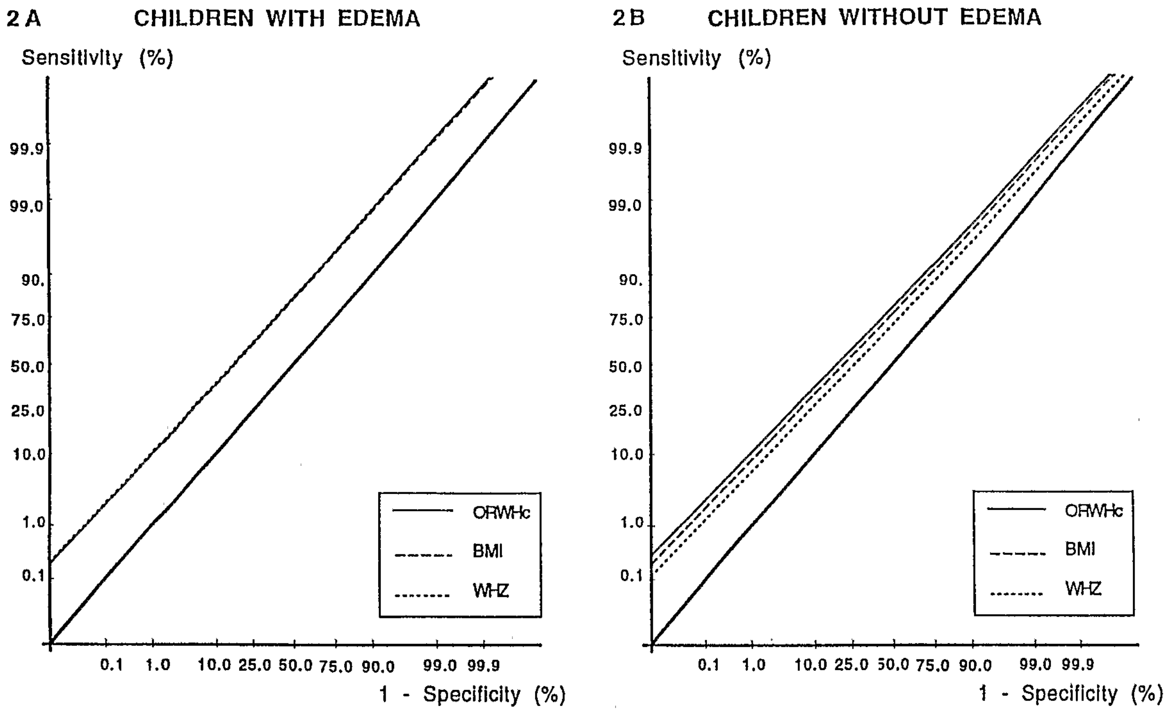

FIGURE 2. Receiver operating curves for the different anthropometric indices expressed in gaussian probability scales, resulting in approximately parallel lines (obtained by the estimation of slope and intercept) in children with edema (A) and without edema (B) in Africa, 1993. ORWHc, common estimate of the optimal ratio of weight to height to assess the risk of death (weight (kg)/height (m)$^{1.74}$); BMI, body mass index (weight (kg)/height (m)^2); WHZ, weight/height index expressed as *z* score, which is the deviation from the median of the National Center for Health Statistics' standard, expressed in multiples of the standard deviation. The curve for the weight/height index expressed as the percentage of the reference median, which was virtually identical with the curve of the body mass index, is not shown.

TABLE 4. Difference of index of detectability (da) calculated from the receiver operating curves expressed in gaussian probability scales between different anthropometric indices (column-row), in children with edema (upper right part of the table) and in children without edema (lower left part of the table) treated in therapeutic feeding centers, Africa, 1993

		Children with edema			
		ORWHc†	BMI†	WHP†	WHZ†
Children without edema	ORWHc		−0.0219	0.0270	0.0130
	BMI	0.1010		0.0489	−0.0349
	WHP	0.1140	0.0130		−0.0140
	WHZ	0.2693*	0.1682*	0.1552**	

* $p < 0.05$; ** $p < 0.01$ (significance of *z*-da test).

† ORWHc, common estimate of the optimal ratio of weight to height to asses the risk of death (weight (kg)/height (m)$^{1.74}$) ; BMI, body mass index (weight (kg)/height (m)^2); WHP, weight/height index expressed as the percentage of the median of the National Center for Health Statistics' standard; WHZ, weight/height index expressed as *z* score, which is the deviation from the median of the National Center for Health Statistics' standard, expressed in multiples of the standard deviation.

weight and height to the risk of death would have to be dramatically different for children who left and those who remained and were included.

Among the indices studied, the ability of ORWHc to predict mortality could not, by construction, be increased by taking height into account. Moreover, the power of height used to calculate the ORWHc appears to be independent of edema, center, and age group, since no interaction between ORWHc and edema, center, or age group was found.

The weight/height index expressed as the percentage of the median was superior to the weight/height index expressed as the *z* score, for assessing the risk of death, among the whole sample and nonedematous malnourished children. This finding agrees with that from a recent study from India, in which no difference was found between the weight/height index expressed as the percentage of the median or *z* score in assessing the risk of death among children hospitalized for diarrhea (30). The percentage of the median is most commonly used in the field, because the *z* score is not easy to calculate and because its underlying concept, leading to large negative scores for the severely malnourished children, is difficult to grasp for health workers with little statistical knowledge. There seems to be no compelling reason to recommend the use of *z* scores to assess mortality risk in feeding centers.

The body mass index (or indices of weight corrected for height) is generally accepted for assessment of obesity in adults (31–33) and is even advocated for children (34). The relation between mortality and high body mass index in adults is well established (35, 36). The body mass index also seems to be valuable to detect undernourished adults (37) and is closely related to their risk of death (38). However, the body mass index has not been recommended for identifying or classification of undernourished children; this is largely because of its variability with age (39). Indeed, we observed that prediction of mortality through the body mass index should be corrected by age group, a result not evidenced for the other tested indicators. Yet, to our knowledge, the value of the body mass index, in relation to other indices, for assessing the risk of death in malnourished children has not been examined.

Both the ORWHc and body mass index, without any correction for age, were as good as, or better than, the weight/height index for predicting death among severely malnourished children.

Anthropometric indices seem to have a better predictive value for mortality among children without edema than for those with edema. This is not surprising as metabolic abnormalities such as hepatic dysfunction (7), immunoincompetence, and electrolyte disturbance (3, 4) are more common in edematous children. Furthermore, the weight recorded on admission includes the weight of edema fluid; thus, edematous children are likely to have the severity of their tissue wasting underestimated to an extent that is itself dependent upon the degree of edema and hence to be highly variable.

The superior ability of the ORWHc to predict death favors its use over the weight/height index to categorize severely malnourished children, especially as the calculation of the ORWHc with a pocket calculator is easier than the calculation of the weight/height index. If a computer is available, the ORWHc can be quickly estimated for many patients by entering their weight and height on widely available spreadsheets without programming knowledge or specialized software. If no pocket calculators able to handle a 1.74 power of a number are available, the body mass index can be used.

The comparison of mortality rates for different therapeutic feeding centers or with different treatment regimens is likely to be much more meaningful where the relative rates are adjusted for the nutritional status of the children: adjustment for the ORWHc or body mass index and edema would be more appropriate than adjustment using the weight/height index.

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REFERENCES

1. Cook R. Is hospital the place for the treatment of malnourished children? J Trop Pediatr Environ Child Health 1971;17:15–25.
2. Van Roosmalen-Wienbenga MW, Kusin JA, de With C. Nutrition rehabilitation in hospital—a waste of time and money? Evaluation of nutrition rehabilitation in a rural district hospital in southwest Tanzania. I. Short-term results. J Trop Pediatr 1986;32:240–3.
3. Gomez F, Ramos Galvan R, Cravioto Munoz J, et al. Mortality in second and third degree malnutrition. J Trop Pediatr 1956;2:77–83.
4. Gurson CT, Yuksel T, Saner G. The short-term prognosis of protein-calorie malnutrition in Marmara region of Turkey. J Trop Pediatr 1976;22:59–62.
5. Dramaix M, Hennart P, Brasseur D, et al. Serum albumin concentration, arm circumference, and oedema and subsequent risk of death in children in central Africa. BMJ 1993;307:710–13.
6. Beau JP, Garenne M, Diop B, et al. Diarrhoea and nutritional status as risk factors of child mortality in a Dakar hospital (Senegal). J Trop Pediatr 1987;33:4–9.
7. McLean AEM. Hepatic failure in malnutrition. Lancet 1962;2:1292–4.
8. McLaren DS, Shirajian E, Loshkajian H, et al. Short-term prognosis in protein-calorie malnutrition. Am J Clin Nutr 1969;22:863–70.
9. Golden MHN, Ramdah DD. Free radicals in the pathogenesis of kwashiorkor. Proc Nutr Soc 1987;46:53–68.
10. McFarlane H, Reddy S, Adcock KJ, et al. Immunity, transferrin, and survival in kwashiorkor. Br Med J 1970;4:268–70.
11. Smith IF, Taiwo O, Golden MHN. Plant protein rehabilitation diets and iron supplementation of the protein-energy malnourished child. Eur J Clin Nutr 1989;43:763–8.
12. Wharton BA, Howells GR, McCance RA. Cardiac failure in kwashiorkor. Lancet 1967;2:384–7.
13. Waterlow JC, Buzina R, Keller W, et al. The presentation and use of height and weight data for comparing nutritional status of groups of children under the age of 10 years. Bull World Health Organ 1977;55:489–98.
14. National Center for Health Statistics. NCHS growth curves for children birth-18 years. United States. Vital Health Stat [11] 1977;165:i-iv, 1–74.
15. World Health Organization. Development of indicators for monitoring progress towards Health for All by the year 2000. Geneva: World Health Organization, 1981. (Health for All series, no. 4).
16. Oxfam Health Unit. Selective feeding programmes. Oxford: Oxfam, 1984.
17. Sullivan KM, Garstein J, Dean AG, et al. The use and availability of anthropometry software. Food Nutr Bull 1990;12:116–19.
18. Siegel S. Nonparametric statistics for the behavioral sciences. New York: McGraw-Hill, 1956:104–10, 116–27.
19. Cox DR, Snell EJ. Analysis of binary data. 2nd ed. London: Chapman and Hall, 1989:66–83.
20. Finney DJ. Statistical methods in biological assay. London: Griffin, 1971:21–38.
21. Cox DR, Snell EJ. Analysis of binary data. 2nd ed. London: Chapman and Hall, 1989:179–83.
22. Searle SR, Speed FM, Milliken GA. Populations marginal means in the linear model: an alternative to least squares means. Am Stat 1980;34:216–21.
23. Shapiro SS, Wilk MB. An analysis of variance test for normality (complete samples). Biometrika 1965;52:591–611.

24. Habicht JP. Some characteristics of indicators of nutritional status for use in screening and surveillance. Am J Clin Nutr 1980;33:531–5.
25. Metz LE. Basic principles of ROC analysis. Semin Nucl Med 1978;8:283–98.
26. Brownie C, Habicht JP, Cogill B. Comparing indicators of health or nutritional status. Am J Epidemiol 1986;124: 1031–44.
27. Dixon WJ, Brown MB, Engelman L, et al. BMDP statistical software. Vol 2. Los Angeles: UCLA Press, 1988.
28. SPSS statistical data analysis. Chicago: SPSS, Inc, 1990.
29. SAS Institute, Inc. SAS/STAT user's guide, version 6. 4th ed. Cary, NC: SAS Institute, Inc, 1989.
30. Sachdev HPS, Satyanarayana L, Kumar S, et al. Classification of nutritional status as z-score or percent of reference median—Does it alter mortality prediction in malnourished children? Int J Epidemiol 1992;21:916–21.
31. Garrow JS, Webster J. Quetelet's index (W/H^2) as a measure of fatness. Int J Obes 1985;9:147–53.
32. Keys A, Fidanza F, Karvonen MJ, et al. Indices of relative weight and obesity. J Chronic Dis 1972;25:329–43.
33. Deurenberg P, Weststrate JA, Seidell JC. Body mass index as a measure of body fatness: age- and sex-specific prediction formulas. Br J Nutr 1991;65:105–14.
34. Rolland-Cachera MF, Bellisle F, Fricker J. Obésité. In: Ricour C, Ghisolfi J, Putet G, et al., eds. Traité de nutrition pédiatrique. Paris: Maloine, 1993:690–723.
35. Dyer AR, Stamler J, Berkson DM, et al. Relationship of relative weight and body mass index to 14-year mortality in the Chicago Peoples Gas Company study. J Chronic Dis 1975;28:109–23.
36. Allebeck P, Bergh C. Height, body mass index, and mortality: Do social factors explain the association? Public Health 1992; 106:375–82.
37. James WPT, Ferro-Luzzi A, Waterlow JC. Definition of chronic energy deficiency in adults. Eur J Clin Nutr 1988;42: 969–81.
38. Henry CJK. Body mass index and the limits of human survival. Eur J Clin Nutr 1990;44:329–35.
39. Rolland-Cachera MF, Sempé M, Guilloud-Bataille M, et al. Adiposity indices in children. Am J Clin Nutr 1982;36: 178–84.

APPENDIX

Determination of the optimal power of height in the ratio of weight to height to assess the risk of death

A usual model to relate fatality rate to exogenous variables is the logistic regression model. In the case of a set of two predictor variables x_1, x_2, the risk of death $P(x_1, x_2)$ is related to these predictors by the relation:

$$P(x_1, x_2) = \{1 + \exp[-(\alpha + \beta_1 x_1 + \beta_2 x_2)]\}^{-1},$$

which is equivalent to a linear relation between the logarithm of the odds of the probability of death with the two covariates:

$$\mathrm{Log}[P/(1 - P)] = \alpha + \beta_1 x_1 + \beta_2 x_2.$$

If x_1 = log weight and x_2 = log height, the model becomes

$$\mathrm{Log}[P/(1 - P)] = \alpha + \beta_1 \text{ log weight} + \beta_2 \text{ log height}. \quad (1)$$

It means that children with the same value of β_1 log weight + β_2 log height have the same estimated risk of death.

The maximum likelihood technique allows us to derive estimates for coefficients β_1 and β_2 (mean ± standard error) of equation 1. Equation 1 may be expressed as:

$$\alpha + \beta_1[\text{log weight} + (\beta_2/\beta_1)\text{log height}]$$

or equivalently:

$$\alpha + \beta_1 \{\log[\text{weight/height}^{-\beta_2/\beta_1}]\}.$$

$\sigma = -\beta_2/\beta_1$ is the power of height in the optimal ratio of weight to height (ORWHc) to estimate the risk of death among malnourished children treated in a feeding center. The risk of death would be the same for any child with the same value of weight/height$^{\sigma}$.

The confidence interval of the σ estimate can be estimated with a method described by Finney (20). Let b_1 and s_{b_1} be the mean and standard error of the β_1 estimate, b_2 and s_{b_2} the mean and standard error of the β_2 estimate, and $r_{b_1 b_2}$ the correlation of these two estimates. The mean of the σ estimate is $-b_2/b_1$.

The variance of this estimate is approximately

$$se_{\sigma}^2 = [s_{b_2}{}^2 - 2\sigma s_{b_1 b_2} + \sigma^2 s_{b_1}{}^2]/b_1{}^2 \text{ with } s_{b_1 b_2} = r_{b_1 b_2} s_{b_1} s_{b_2}.$$

Ninety-five percent confidence interval limits of the σ estimate are approximately $-b_2/b_1 \pm t_{ddl,\,95\%}\, se_{\sigma}$, where *ddl* is the number of degrees of freedom of the logistic model.

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