Original Research Communications—methods

Weight-for-height indices to assess nutritional status—a new index on a slide-rule[1, 2]

T. J. Cole, M. L. Donnet,[3] and J. P. Stanfield[4]

ABSTRACT The protein-energy malnutrition classification schemes of Waterlow and McLaren, although similar in other respects, assess the weight-for-height of children in quite different ways. The drawbacks of their two methods are described, and an alternative method is presented which overcomes them. The new index is called weight/height^2-for-age, and consists of the ratio weight/height^2 expressed as a percentage of the same ratio for a reference child of the same age. Although the index is not age independent, it is insensitive to all but the grossest errors in age for children over 12 months old. The index is equally appropriate for the assessment of obesity. A slide-rule based on the Tanner standard is available to do the calculation. *Am. J. Clin. Nutr.* 34: 1935–1943, 1981.

KEY WORDS Nutrition, nutritional assessment, nutritional calculation, protein-energy malnutrition, obesity, anthropometry, weight height indices

Introduction

The assessment of weight-for-height has long been important in the classification of both protein-energy malnutrition (PEM) and obesity (1–3). Thus it is surprising that there is still disagreement about how to determine weight-for-height in children. Waterlow (4) reviewed various methods, and concluded that comparing the child's weight with his or her expected weight-for-height using the Harvard, or more recently American (5), standard was the best approach. The advantage of this method is that it does not involve the child's age, which is often either unknown or unreliable.

However Van Wieringen (6) has shown that during the 1st yr of life, children of a given height tend to weigh more the older they are. Because the weight-for-height standard takes no account of age, it is slightly biased.

To include age in the assessment, McLaren and Read (2, 3) suggested comparing the child's weight/height ratio to the same ratio obtained for a reference child of the same age, but this has also been criticized as giving results that are too extreme (4, 7, 8). For example, the weight-for-height of a marginally stunted infant (90% height-for-age) is 15% less by the weight/height ratio than by the weight-for-height standard.

Despite their shortcomings, both methods are used very widely for assessing weight-for-height. As an alternative, this paper describes a new index that standardizes weight for both height and age (9). It is illustrated here using data from the 1st yr of life, where the other two indices disagree most.

The index consists of the ratio weight/height^2 expressed as a percentage of the same ratio for a reference child of the same age and sex. It can also be calculated as % weight-for-age/ (% height-for-age/100)^2.

[1]From the MRC Dunn Nutrition Unit, Cambridge CB4 1XJ, England and the Glasgow University Social Paediatric and Obstetric Research Unit Glasgow G12 8LS, Scotland.

[2]Address reprint requests to: J.T. Cole, MRC Dunn Nutrition Unit, Cambridge CB4 1XJ, England.

[3]Supported by a grant from the Scottish Home and Health Department.

[4]Present address: International Child Health Unit, Royal Victoria Infirmary, Newcastle-upon-Tyne NE1 4LP, England.

Materials and methods

The data are from a social class stratified random sample of Glasgow infants, seen cross-sectionally in five age groups: 6 wk, 3, 6, 9, and 12 months, within narrow limits of a few days on either side. A total of 651 children was seen.

Weight and supine length were measured by one observer and an assistant using a length board and a beam balance. However, as it is usual to measure height rather than length in children aged over 2 yr, to avoid repetition the term "height" is used here to cover both height and length. Length rather than height is implied for children under 2 yr old.

Height and weight were expressed as fractions of the median for each age-sex group, and regression analysis was carried out on their natural logarithms.

Results

Table 1 gives the numbers of children, their age ranges, and the medians of height and weight for each age-sex group.

Figure 1 shows the log-log plot of weight against height for all 651 children, and the fitted regression line. The equation of the line is

$$\log(\text{weight}) = \log(21.6) + 2.60 \times \log(\text{height})$$

or equivalently

$$\text{weight} = 21.6 \times \text{height}^{2.60} \qquad (1)$$

The correlation is 0.96, the residual SD 0.087 log units (about 8.7%), and the slope (i.e., the power of height) has a SE of 0.03.

The five age groups in Figure 1 have different plotting symbols, which show that within each age group the weight-height correlation is appreciably less than for the age groups combined. The effect of this on the regression slope can be seen in **Table 2**, which gives the results for each age-sex group separately. All the regression slopes (or height powers) except one are less than the overall slope, and all but two have slopes between 1.7 and 2.3. This flattening phenomenon is illustrated in **Figure 2**, with the age-sex group *lines* shown as *solid* and the overall *line dotted*.

If the separate lines are constrained to be parallel, they give an average regression slope of 2.10 ± 0.09, highly significantly shallower ($p < 0.001$) than for the overall line. The residual SD is also slightly less than for the overall line, at 0.083 log units (8.3%).

Thus the weight-height relationship is closer when each age is treated separately than when the whole age range is taken together. Taken at face value, this implies that for the 1st yr of life at least, a separate weight-for-height line should be used for every age group. The same suggestion has been made elsewhere (5).

However, there is a simpler solution, which with few assumptions enables all the separate lines to be viewed as a single line. It relies on the statistical principle that a regression line passes through the mean of the data. Each regression line in Figure 2 passes through the mean height and weight for that age-sex group. (In fact the means are geometric rather than arithmetic means, due to the log transformation.)

Imagine that the data in Figure 1 are replotted on a series of transparencies, one transparency to each group. When all viewed together, they obviously look the same as Figure 1. However, if they are put on top of each other so that the mean heights and weights for the different groups coincide, it causes all the individual regression lines to cross at the origin of means.

This process of superimposing transparencies is mathematically equivalent to expressing the heights and weights as fractions of the mean for age and sex—each fraction takes the value 1 at the origin of means.

The difficulty here is that in general, published growth standards quote the median rather than the mean for height and weight, and the two quantities are not identical. It is also common practice to express weight and height as fractions (or percentages) of the median. To follow this convention, weight-

TABLE 1
Details of the Glasgow children by age-sex group

Age	Sex	n	Age range	50th percentile H	50th percentile W
			yr	*mm*	*kg*
6 wk	M	72	0.110–0.123	555	4.57
	F	61	0.099–0.123	534	4.14
3 mo	M	82	0.244–0.258	604	5.90
	F	86	0.244–0.258	590	5.53
6 mo	M	64	0.493–0.510	670	7.45
	F	54	0.493–0.510	650	7.10
9 mo	M	60	0.745–0.767	708	9.13
	F	60	0.745–0.767	695	8.46
12 mo	M	52	0.995–1.011	750	9.88
	F	60	0.995–1.011	732	9.32

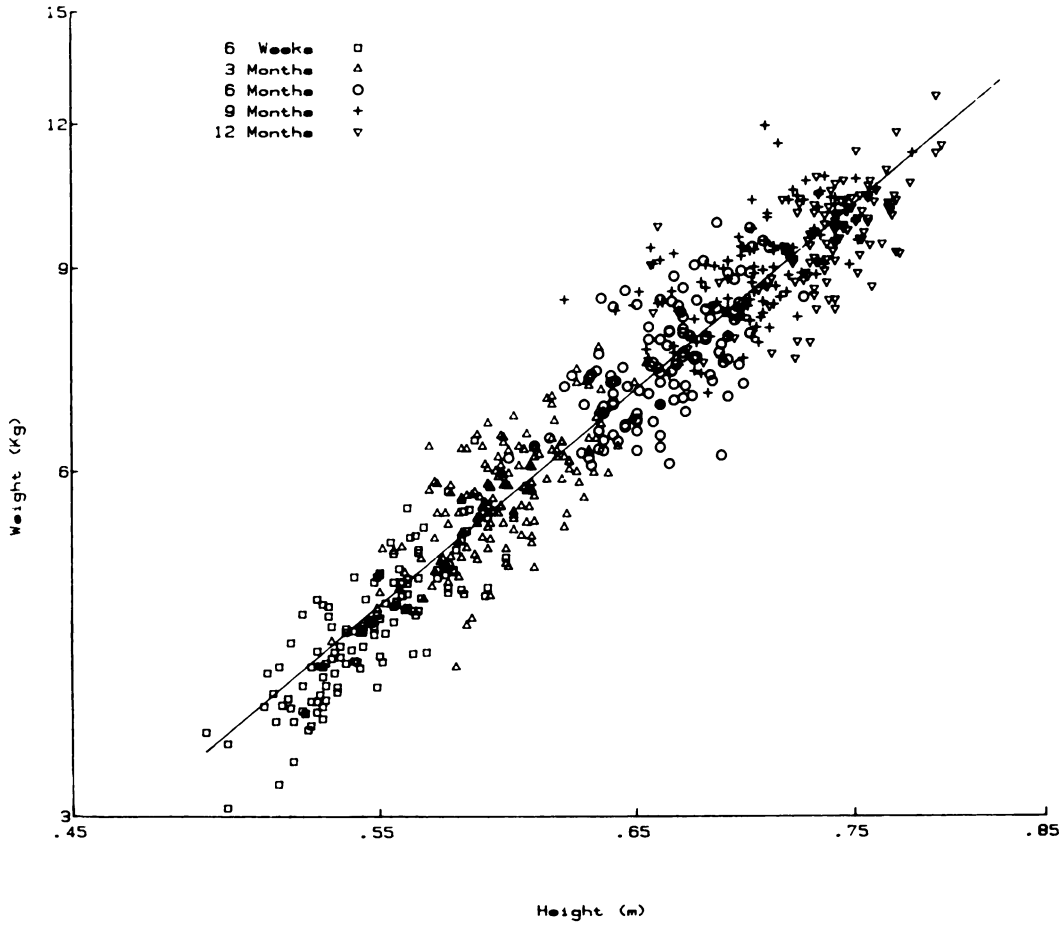

FIG. 1. Plot of weight versus height for 651 Glasgow children in five age groups with the fitted *regression line*.

TABLE 2
Details of the regressions in each age-sex group, and combined

Age	Sex	Regression of weight on height			Regression of weight-for-age on height-for-age		
		Slope		Constant	Slope		Constant
			se			*se*	
6 wk	M	2.3	(0.2)	17.9	2.3	(0.2)	1.01
	F	3.1	(0.2)	28.5	3.1	(0.2)	1.01
3 mo	M	2.1	(0.2)	17.2	2.1	(0.2)	1.02
	F	2.1	(0.2)	17.2	2.1	(0.2)	1.00
6 mo	M	2.2	(0.3)	18.3	2.2	(0.3)	1.01
	F	2.0	(0.4)	17.2	2.0	(0.4)	0.98
9 mo	M	2.1	(0.3)	19.1	2.1	(0.3)	1.00
	F	1.2	(0.3)	13.4	1.2	(0.3)	1.02
12 mo	M	2.2	(0.4)	18.7	2.2	(0.4)	1.02
	F	1.7	(0.3)	16.0	1.7	(0.3)	1.00
Combined		2.60	(0.03)	21.6	2.10	(0.09)	1.008

for-age is here defined as weight, expressed as a fraction of the median weight for the child's age-sex group. Height-for-age is defined similarly.

Figures 3 and **4** show the results of "superimposing transparencies" for the separate groups—plots of weight-for-age against height-for-age. The origin represents the medians of height and weight rather than the means, and this explains why in Figure 3 the regression lines do not quite cross at the origin. However, they are clearly very close, and the intercepts (Table 2) are all within 2% of unity.

Since the lines are so similar both in slope and intercept, it is reasonable to combine the groups and fit an overall regression line. This is shown dotted in Figure 3, and also in Figure 4 superimposed on the original data.

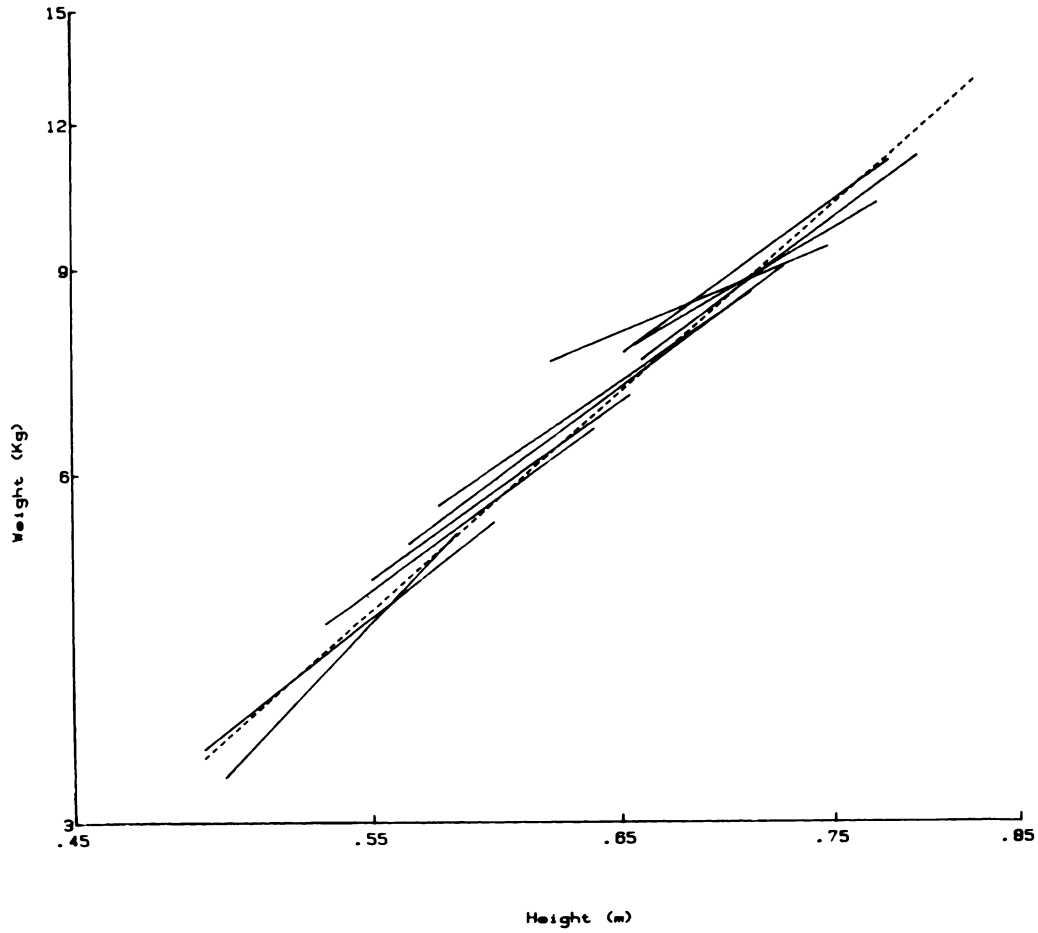

FIG. 2. Regression lines of weight-for-height for Glasgow children grouped according to age and sex. The *regression line* for all the children combined is shown dotted.

The equation of the line is

$$\text{weight-for-age} = 1.008 \times \text{height-for-age}^{2.10},$$

with correlation 0.68, residual SD 0.083 log units, and a SE of 0.09 for the slope. It provides as good a fit to the data as the 10 separate lines of Figure 3 ($P > 0.05$).

Moreover, it can be further simplified, since the intercept is close to 1 and the slope to 2. The final equation is thus

$$\text{weight-for-age} = \text{height-for-age}^2 \quad (2)$$

which again has a residual SD of 0.083 log units (8.3%). Expressed in words, equation (*2*) says that the *expected* weight-for-age for a child of known height-for-age is given by the square of the child's height-for-age. His *actual* weight-for-age can then be expressed as a fraction of this figure, to give a measure of his weight-for-height.

Also, equation (*2*) can be rearranged to show that the expected value of weight/height^2 for a child is given by the same ratio for a reference child of the same age. Thus the child's actual weight/height^2, expressed as a fraction of the reference value is an equivalent measure of his weight-for-height. This justifies the name weight/height^2-for-age given to the index.

Discussion

The use of weight-for-height as an index of PEM has become widespread over the last 10 yr. The index relies on the concept of a weight-for-height standard, a chart or table giving reference values of weight for different heights. An individual child's weight is compared to the reference value corresponding to his height.

The shape of the chart is derived by clas-

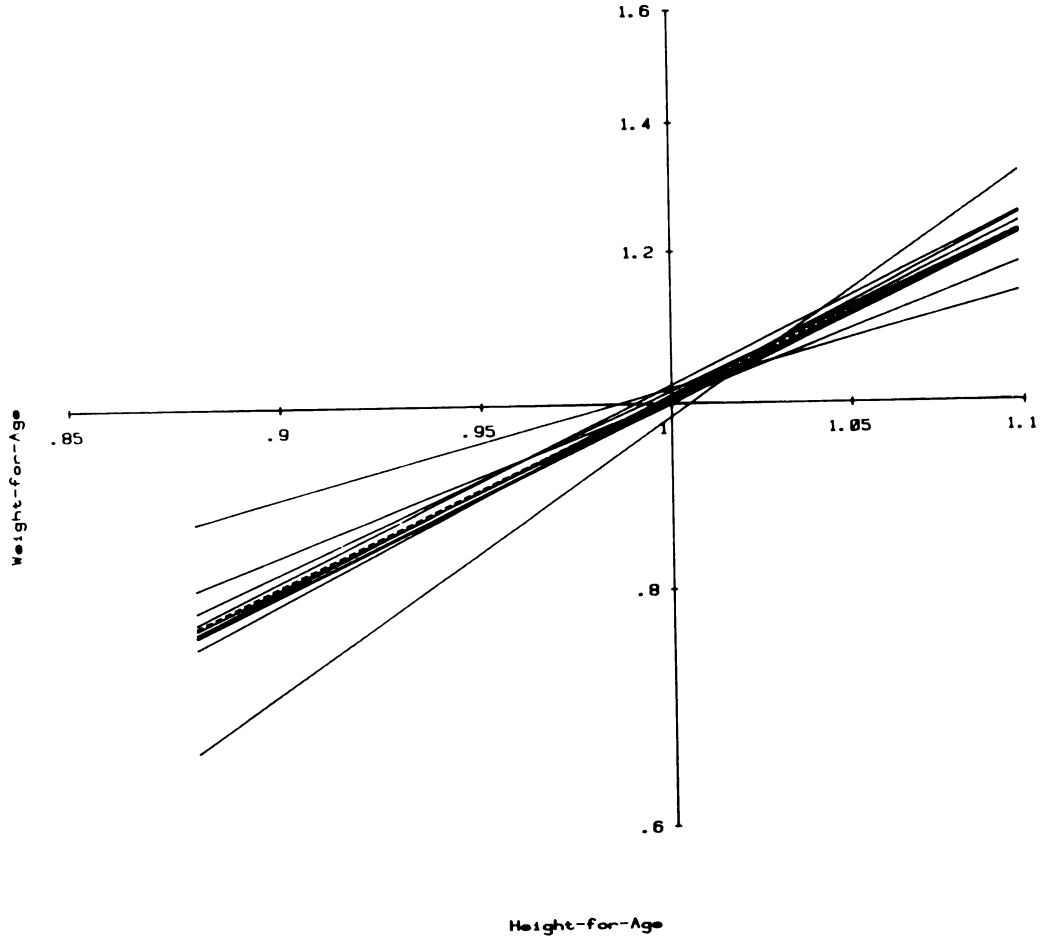

FIG. 3. Regression lines of weight-for-age on height-for-age for Glasgow children grouped according to age and sex. The *regression line* for all the children combined is shown dotted.

sifying children from the reference population by height, and deriving the mean weights for each height class. As the procedure takes no account of age, age is not required when the chart is used for assessment.

The regression line (1) fitted to the data of Figure 1 is a weight-for-height standard in that it gives the mean (or expected) weights of Glasgow children at different heights. A straight-line relationship is assumed here as the age range is relatively narrow, but over a wider age range a curvilinear standard would usually be fitted.

The slope of 2.6 for the Glasgow line indicates that during the 1st yr, each 1% increase in height is associated with an increase of 2.6% in weight, on the average. The figure of 2.6 is dictated largely by the differences between the age groups, to the extent that a regression line fitted to just the group medians of height and weight also gives a slope of 2.60. With just 10 points the line has a correlation of 0.997. In other words, the weight-height relationship *within* each group has very little influence on the slope of the weight-for-height standard.

To take advantage of the information contained in each age group, the between-group differences need to be removed. This is done here by the familiar method of expressing height and weight as fractions of reference values for the child's age, a method which McLaren and Read (2, 3) also propose. The one difference between their approach and ours is that they assume the index weight-for-age/height-for-age to be appropriate, whereas in fact weight-for-age/height-for-age[2] is far better statistically (in other words

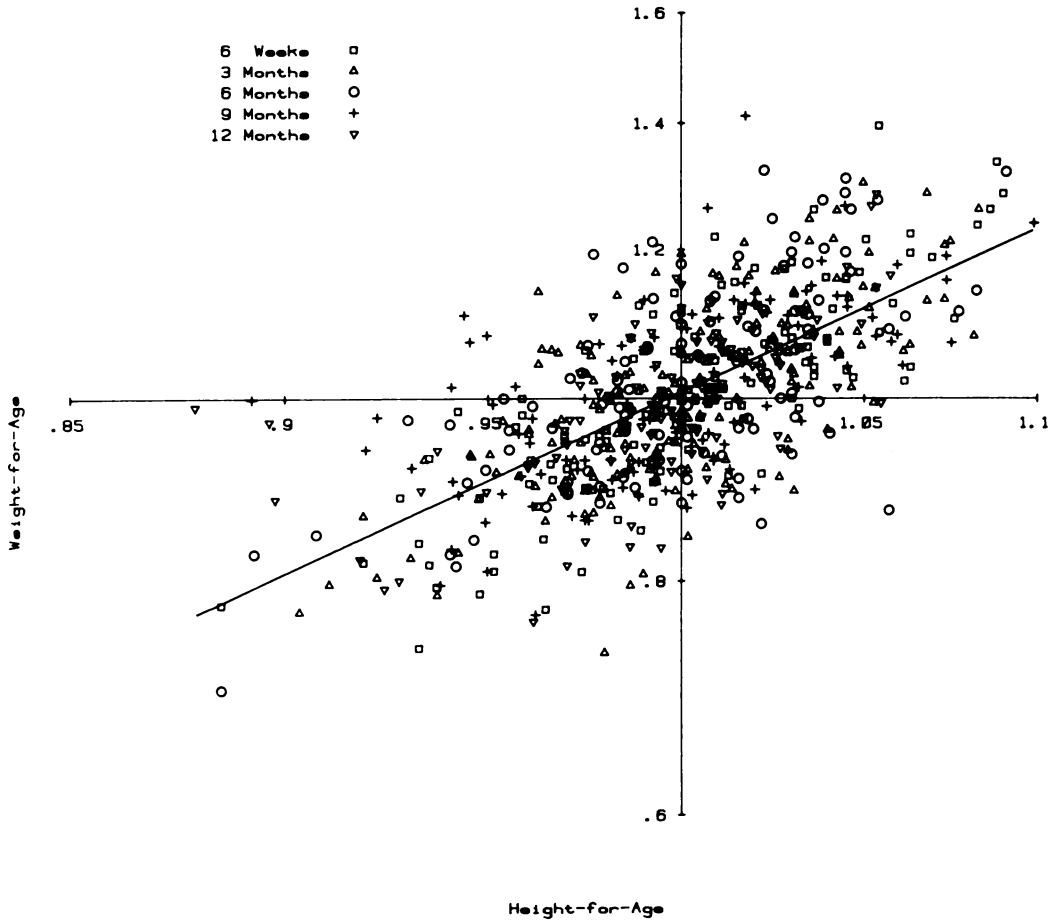

FIG. 4. Plot of weight-for-age versus height-for-age for 651 Glasgow children in five age groups with the fitted *regression line.*

the regression slope is much closer to 2 than to 1).

What then *is* the importance of the regression slope? As an example, consider a stunted child whose height is 0.9 (i.e., 90%) of the reference value for age. Since he is short for his age, his expected weight is also less than average, by an amount which depends on the regression slope. If the slope is 2.6, his expected weight for his height is $0.9^{2.6}$, or 0.76, times his expected weight for his age. If the slope is 2, this figure is 0.9^2, or 0.81. Furthermore, McLaren's weight-height ratio which corresponds to a slope of 1, leads to a figure of 0.9^1, or 0.9. Thus this stunted child's expected weight using the Glasgow weight for height standard is only 84% (0.76 as against 0.9) of his expected weight based on McLaren's ratio. Weight/height^2-for-age gives an intermediate figure.

A low expected weight divided into the child's actual weight leads to a high assessment of weight-for-height; thus the Glasgow (or any other) standard gives an optimistic assessment of weight-for-height. Conversely, use of the weight-height ratio gives a pessimistic result. Weight/height^2-for-age is somewhere in-between.

Table 3 illustrates this discussion by comparing the three indices of weight-for-height for three children, using as reference the growth standard of Jelliffe (10). Child A is stunted, B is very tall, and C is average. The results for child A are as already described, an optimistic assessment from the weight for height standard and a pessimistic weight-

height ratio. Child B, who is tall, shows exactly the opposite effect. Child C shows that for average children the three indices are in agreement.

The argument so far has ignored the fact that weight-for-height standards are usually curved. Generally speaking the slope falls from about 3 at birth to nearer 2.5 later in the 1st yr. Then at about 12 months there is a sudden fall in slope to around 1.6, where it stays until age 5 and beyond (9). Why it should do this is not clear. The Glasgow standard, so far as it goes, accords with this general pattern. Cole (9) shows that the within-age slope remains near 2 throughout this period, so that weight/height^2-for-age is a valid index until well beyond 5 yr.

The change in slope at 12 months has a dramatic and serious effect on the weight for height standard's assessment. It is illustrated in **Figure 5** using child A of Table 3, who is assumed to remain at 90% height-for-age, 81% weight-for-age (Jelliffe standard) from 3 through to 60 months of age. During the 1st

TABLE 3
Weight-for-height in stunted, tall, and average children

	Child		
	A	B	C
Age (mo)	6	3	9
Height (mm)	592	650	707
Weight (kg)	6.0	6.7	7.2
Height-for-age	90%	108%	100%
Weight-for-age	81%	118%	81%
Weight for height standard	108%	93%	81%
Weight/height ratio	90%	108%	81%
Weight/height^2-for-age	100%	100%	81%

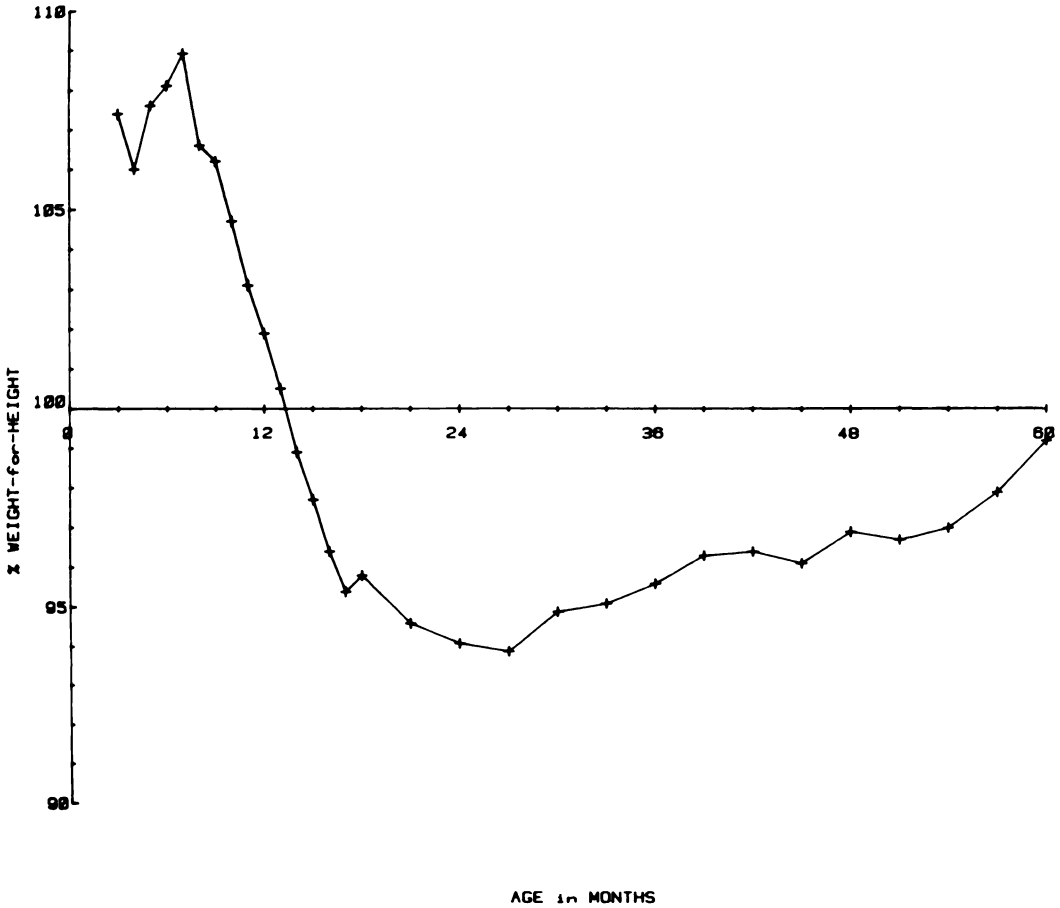

FIG. 5. Weight-for-height, assessed using the Jelliffe standard, for a child whose height-for-age and weight-for-age remain constant at 90 and 81%, respectively over the age range 3 to 60 months.

yr the assessment is optimistic at about 108%, but around 12 months it suddenly drops to 95%, even though weight-for-age and height-for-age have not changed. This is a serious disadvantage of all weight for height standards, and indeed other indices based on weight for height standards (11, 12).

The other two indices in contrast give a constant assessment throughout—100% for weight/height^2-for-age and 90% for the weight-height ratio. Taking 100% as the correct figure, the weight for height standard underestimates the prevalence of PEM during the 1st yr and exaggerates it subsequently. The weight-height ratio seriously exaggerates it throughout. Thus for children over 1 yr old, both the commonly used indices overestimate the prevalence of PEM.

The ratio weight/height^2 has been suggested as an age-independent index of weight-for-height in children (13, 14)—the same index is widely used for adults (15, 16). Van Wieringen (6) has shown that weight/height^2 in Dutch children falls slightly between 1 and 6 yr, but rises very steeply during the 1st yr. This is another reflection of the fact that the weight-height slope is steeper during the 1st yr than subsequently. Thus weight/height^2 by itself is unsuitable at this time, unless standardized for age.

After 1 yr it changes relatively little with age, and so is a reasonably good index. The corollary of this is that reference values of weight/height^2 do not change much with age either, so that when using weight-height^2-for-age, the child's age need not be specified with great accuracy. This is an obvious advantage in parts of the world where childrens ages are hard to obtain. During the 1st yr when age is more important, it is at the same time easier to establish, for example by using an events calendar.

Weight/height^2-for-age has been demonstrated using both the Glasgow and Jelliffe (10) reference standards. In principle it can be used with any growth standard, always assuming that the mean value of the index is relatively constant with age in the group

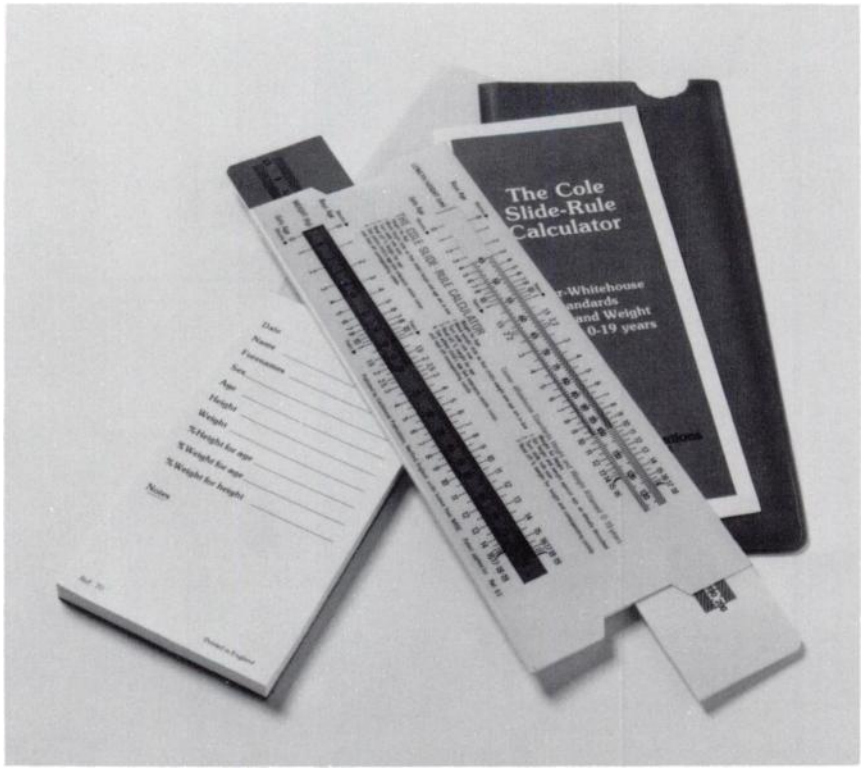

FIG. 6. The slide-rule provides height-for-age, weight-for-age, and weight-for-height based on the Tanner standard.

being considered. Where this does not hold, the obvious answer is to treat the data in narrow age groups.

To simplify calculation of the index a slide-rule has been devised to do the sum directly (**Fig. 6**). Based on the Tanner (17) standard it also provides seven percentiles of height and weight, and indicates the presence of wasting (weight-for-height below 80%) and stunting (height-for-age below 90%).

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The slide-rule is available from Castlemead Publications (Reference 63), Creaseys of Hertford Ltd., Castlemead, Hertford, SG14 1LH, U.K. For use in the developing world, it can also be obtained from: Teaching Aids at Low Cost (TALC), Institute of Child Health, 30 Guilford Street, London WC1N 1EH, U.K.

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