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NUTRITIONAL STATUS, AGE AND SURVIVAL: THE MUSCLE MASS HYPOTHESIS

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The relevance of nutritional indices derived from comparison with growth standards to assess the risk of dying was evaluated in a 2-year prospective study in rural Senegal. An average of 3151 children aged 6–59 months were measured twice a year and followed up during the intervening 6-month periods. Children who survived and those who died during follow-up were found to differ more by anthropometric measures directly related to absolute muscle mass (viz. weight, height or arm circumference) than by nutritional indices obtained from comparison with growth standards (weight-for-age, weight-for-height and height-for-age). The findings could not be explained by a confounding effect of age. This brings into question the current approach used to identify high-risk children.

Muscle has a low basal oxygen consumption. Muscle tissue represents an important source of amino acids which can be used, if necessary, to produce glucose and energy (Lehninger, 1975). In contrast, organs such as the brain, heart and kidney account for more than 50 per cent of total oxygen consumption in children but have virtually no energy reserves (Holliday, 1971). The brain is the most energy-requiring organ and almost exclusively uses glucose as a source of energy (Lehninger, 1975). Thus, it could be argued that when energy balance is negative, either due to food shortage or to intercurrent infection, survival is likely to be related to the ratio between muscle mass and the mass of energy-demanding organs, especially the brain. After early infancy, however, the brain grows slowly (Vahlquist, 1979) and seems to be protected in malnutrition (Viteri, 1981). This suggests that muscle mass could be the main determinant of child survival, brain weight showing little variation between individuals.

In previous analyses of the relation between nutritional status and survival and in previous attempts to determine which indicators are the most closely related to the risk of dying (Kielman & McCord, 1978; Chen, Chowdhury & Huffman, 1980; Heywood, 1982; Kasongo Project Team, 1983; Briend *et al.*, 1986), it was taken for granted that survival was determined by the ratio between the observed weight, height or mid-upper arm circumference (MUAC) and a growth standard. We will refer to this as the 'standard hypothesis'.

If muscle mass determines survival, our approach to recognizing high-risk children may have to be reassessed: measures directly related to muscle mass, and not

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their ratio with growth standards, should be the most suitable for identifying children with a high risk of dying.

In this analysis, we compared the likelihood of this 'muscle mass' hypothesis to that of the 'standard hypothesis' by examining the relation between nutritional status, age and survival in children under 5 years of age from rural Senegal.

Data and methods

This analysis was performed using data from a study on the relationship between nutritional status and mortality carried out between March 1983 and June 1985 in rural Senegal. The study was undertaken in 30 villages which had been under demographic surveillance since 1962 (Cantrelle, 1969). It was part of a comprehensive investigation of child health and survival in rural Senegal. The methods and main results have been described elsewhere (Garenne *et al.*, 1987). The study area of about 150 square km surrounded the village of Ngayokhem (region of Fatick). At that time, the total population was about 24 000. The climate is Sahelian and the inhabitants live mainly by agriculture, growing millet and groundnuts during the 3 months of the rainy season.

Survey teams, always including a physician, visited the study villages four times at 6-month intervals between May 1983 and October 1984. Mothers were invited to present their children who were weighed and measured using standard techniques (Jelliffe, 1966). Weight was measured to the nearest 10 g on beam balances (Seca, Hamburg, RFA and Detecto, Brooklyn, USA) regularly checked with standard weights. Height was measured to the nearest mm with a digital length board or a stadiometer (Holtain, Crymich, UK). Mid-upper arm circumference and head circumference were measured to the nearest mm with a fibreglass tape. Triceps skinfold thickness was determined with a standard calliper (Tanner model, Holtain, Crymich, UK).

All data collected during the anthropometric surveys were entered on a computer and, after consistency checking, nutritional indices were calculated as percentages of the NCHS median (NCHS, 1977, 1981; WHO Working Group, 1986). For infants, the index MUAC-for-age was calculated using a Swedish standard which was close to NCHS standard at 1 year of age (Karlberg *et al.*, 1968).

A census of the study area was updated yearly by a team of trained field workers under the supervision of a demographer (MG). Death registration was comprehensive. Dates of births and deaths were usually accurately known or were determined using a local calendar based on agricultural events and Muslim and Christian festivals.

The anthropometric survey included on average 88.5 per cent of all eligible children. There was no difference in survival among children present or absent during anthropometric surveys and this sample can be considered as representative of the area with respect to mortality.

Survival data were analysed by child-semesters: a child was considered as a survivor if it was alive 6 months after anthropometric measurement and was entered as a new child for the following 6 months. Only children aged between 6 and 59 months at the time of anthropometric measurement were included in the analysis. Demographic surveillance was continued after the last anthropometric survey and the follow-up of the last child semester was complete.

Standard statistical techniques were used both for univariate and bivariate analyses and for multiple linear regression (Armitage, 1971). The ability of the anthropometric indicators to differentiate between children who died and those who survived was first assessed by their normalized distance (Habicht, Meyers & Brownie, 1982; Cogill, 1982). This distance, which represents the difference of each indicator between children who died and those who survived expressed in standard deviation units, is highest for indicators which are the most different between the two groups.

Sensitivity, specificity, true positive (TP) ratio and false positive (FP) ratio of each anthropometric index for different cut-off points were also calculated (Habicht, 1980). For that 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 numbers of children who died or who survived in the follow-up in each category were counted (Table 1). For any given cut-off point, the sensitivity of the indicator was the proportion, among all children who died, of those who had been put in the high-risk category. The specificity was the proportion, among all children who survived, of those who had been put in the low-risk category (Table 1). The TP ratio was equal to the sensitivity whereas the FP ratio, representing the proportion among children who survived of those who had been put in the high-risk category, was equal to 1 − specificity (Table 1).

Sensitivity, TP ratio and FP ratio vary in opposite directions from specificity when a new cut-off point is chosen. In other words, each cut-off point represents a different trade-off between sensitivity and specificity or between TP and FP ratios. This trade-off can be represented graphically by plotting the TP ratio against the FP ratio. The resulting plot is known as the receiver-operating-characteristic curve, or ROC curve (McNeil, Keeler & Adelstein, 1975) and can be used to rank different risk factors for their ability to recognize high-risk children: indices which are the most suitable for that purpose have the highest TP ratio for any given FP ratio and have the highest ROC curve on the graph.

Table 1. *Definition of sensitivity, specificity, true positive ratio and false positive ratio for the risk of dying in relation to different cut-off points.*

	Died	*Survived*
High-risk (below cut-off point)	a	b
Low-risk (above cut-off point)	c	d

Sensitivity = true positive ratio = a/(a + c).
Specificity = d/(b + d).
False positive ratio = 1 − specificity = b/(b + d).

The sum of sensitivity and specificity also varies for different cut-off points and goes through a maximum when specificity varies from 0 to 1. This maximum, the maximum sum of sensitivity and specificity (MSS) also gives an estimate of the value of an indicator to recognize children with a high risk of dying (Habicht *et al.*, 1982; Cogill, 1982).

For anthropometric indices with roughly parallel ROC curves, the differences in normalized distance between two groups of individuals can be tested using the Zd_a statistic which has a normal distribution (Brownie, Habicht & Cogill, 1986). When the ROC curves cross each other, this test cannot be used.

For multivariate analysis with survival as outcome, logistic regression models were used. This approach assumes that for a given set of predictor variables $x_1, x_2, \ldots x_k$, the risk of dying, P(x) is related to these predictors by the relation:

$$P(x) = \{1 + \exp[-(a + \beta_1 x_1 + \beta_2 x_2 \ldots + \beta_k x_k)]\}^{-1}$$

This mathematical model is usually recommended to analyse determinants of an outcome which can take only two values, such as survival or death (Kleinbaum, Kupper & Morgenstern, 1982). For each set of predictors, coefficients which described best the association between the observed outcomes and predictors were estimated by iteration by a computer programme. In this analysis, death was coded 1 and survival 0. The coefficients $\beta_1, \beta_2 \ldots \beta_k$ were positive when the higher values of the predictor variables $x_1, x_2 \ldots x_k$ were associated with a higher risk of dying and negative when the higher values of $x_1, x_2 \ldots x_k$ were associated with a lower risk of dying. These coefficients $\beta_1, \beta_2 \ldots \beta_k$ indicate how rapidly the risk of dying increases when the variables $x_1, x_2 \ldots x_k$ increase.

To determine whether it is valid to describe the observed relation between the predictor variable and the outcome by a logistic model, goodness of fit of the logistic model can be assessed by the Hosmer-Lemeshow statistic (Lemeshow & Hosmer, 1982). In all the models presented here, this statistic suggested that the logistic models described the data adequately. The percentage of children who died who were classified in the top fifth risk group by the model also gives an indication of its validity to assess the risk of dying (Lemeshow & Hosmer, 1982).

For each logistical model, a log likelihood statistic is calculated. This statistic indicates how much of the variability of the risk of dying is explained by the predictors. The value of two logistic models to estimate the risk of dying can be compared statistically if all the predictors of one model are included in the second one. In that case, the significance of the additional predictors of the second model can be formally tested by the likelihood ratio statistic $(-2\ln$ maximized likelihood$)$ of the two models: this difference has a chi-square distribution with a degree of freedom equal to the difference in number of predictors (Kleinbaum *et al.*, 1982).

Results

In total, 12 605 child-semesters were available for analysis, an average of 3151 per round. During follow-up, 301 children died (mortality rate: 47.8 per 1000 per year). Mortality rates (and thus risk of dying) were related to age at the time of examination: 71.6 per thousand for children below 36 months of age compared to 15.6 per thousand for children above 36 months ($P < 0.001$).

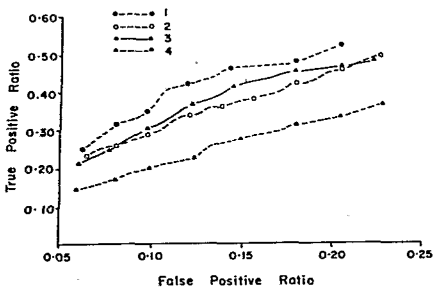

Figure. *Receiver-operating-characteristic (ROC) curves of mid-upper arm circumference (MUAC) and other indicators of nutritional status. 1: MUAC; 2: weight-for-age; 3: weight-for-height; 4: height-for-age.*

Age, anthropometric measures and derived nutritional indices of children who died during the intervals and of those who survived are presented in Table 2. All differences of means between the two groups were significant ($P < 0.001$). The normalized distance between the means of these indicators for children who died and those who survived and their MSS both suggest that the two groups of children differed more in terms of measures directly related to muscle mass such as weight, height and MUAC than by nutritional indices adjusted for age or height. This assumption was tested for statistical significance by a Zd_a test for MUAC which had a ROC curve consistently above those of age-corrected nutritional indices (Figure). MUAC was found to be a significantly more reliable indicator of the likelihood of dying than weight-for-age, weight-for-height and height-for-age (Table 2). The ROC curves of weight and height went below that of other nutritional indices for low FP ratios and the differences between their normalized distances could not be tested.

Children who died were on average younger than those who survived (mean age during rounds: 22.6 months s.d.12.5 *versus* 31.5 months s.d.15.8, $P < 0.001$). Because weight, height and MUAC increase with age whereas the risk of dying decreases, the possibility of an association between direct anthropometric values and risk of dying due to the confounding effect of age had to be considered. This was done by examining the relationship between different anthropometric measures, indicators of nutritional status and risk of dying in a series of logistic regression models. This approach was also used to test the respective likelihood of the muscle mass and of the standard hypotheses.

Table 2. *Means and standard deviations of anthropometric indicators and age of surviving and dead children.*

Anthropometric indicators	*Survivors* (*n = 12304*)[4] *Mean*	*s.d.*	*Dead* (n = 301)[4] *Mean*	*s.d.*	d_a[1]	*MSS*[2]	Zd_a[3]
Weight (kg)	11.65	3.28	9.15	2.40	0.87	139.5	n.a.[5]
Weight-for-age (%)	86.7	12.4	78.3	13.1	0.66	131.0	2.88*
Weight-for-height (%)	95.0	9.2	89.1	10.5	0.60	128.2	4.41**
Height (mm)	86	12	78	9	0.78	138.8	n.a.
Height-for-age (%)	95.5	5.2	93.3	5.5	0.40	117.8	5.40**
MUAC (mm)	143	13	132	14	0.79	135.6	—
MUAC-for-age (%)	85.8	8.0	80.5	9.6	0.60	130.8	n.a.
Age (months)	31	16	22	12	0.62	131.7	n.a.

[1] Normalized distance.
[2] Maximum sum of specificity and sensitivity (%).
[3] Z_{da} test comparing the discriminating power of MUAC with that of different nutritional indices.
[4] Number of child-semesters.
[5] n.a.: not applicable, non-parallel ROC curves.
*$P < 0.01$; **$P < 0.001$.

Since comparisons of ROC curves suggested that MUAC was the predictor which predicted best the risk of dying (Figure), a first set of models was built by adding different predictors to MUAC in a series of logistic models (Table 3). MUAC and age were both independently related to child survival (model 1.2, Table 3). In model 1.2 (Table 3), both MUAC and age had a negative coefficient which means that for a given MUAC, older children had a higher chance of survival. This result, however, is not compatible with the standard hypothesis, since for a given MUAC, older children have a lower MUAC-for-age and a lower weight-for-age as shown by multiple regression (Table 4, models 1 and 2) and should have a higher risk of dying according to the standard hypothesis. In the same way, height and MUAC were both independently related to child survival (models 1.1 and 1.3, Table 3) and in both models height and MUAC had a negative coefficient. Hence, for a given MUAC, taller children had a higher chance of survival. This finding also is not compatible with the standard hypothesis: for a given MUAC, taller children have a lower weight-for-height (Table 4, model 3) and should have a higher risk of dying according to the standard hypothesis.

When MUAC and height were already included in the model, survival was not significantly related to the age of the child (model 1.4, Table 3). This suggests that the relation between MUAC, height and survival is unlikely to be due to the confounding effect of age.

A comparison of models 1.3, 1.5, 1.6 and 1.7 (Table 3) also suggests that the relation between nutritional status, as assessed by weight-for-height (but not by weight-for-age or height-for-age) and risk of dying could be explained by its relation with height and MUAC.

Another series of logistic models was built using weight as initial predictor, since the comparison of normalized distance and MSS (Table 2) suggested that it

Table 3. *Comparison of different logistic regression models for the estimation of the risk of dying with MUAC, age, height and head circumference as predictors.*

Predictors ($x_1, x_2, \ldots x_k$)			β	*log likelihood statistic*	*% of dead children in highest risk fifth*
1.1	(a)	MUAC	−0.0565**	186.99	47.8
1.2	(a)	MUAC	−0.0477**	206.30	46.5
	(b)	Age	−0.0199**		
1.3	(a)	MUAC	−0.0413**	216.59	47.2
	(b)	Height	−0.0351**		
1.4	(a)	MUAC	−0.0395**	218.41	49.2
	(b)	Height	−0.0054**		
	(c)	Age	0.0145$^{\text{n.s.}}$		
1.5	(a)	MUAC	−0.0307**	220.94	48.5
	(b)	Height	−0.0036**		
	(c)	Weight-for-age	−0.0153*		
1.6	(a)	MUAC	−0.0307**	220.20	48.2
	(b)	Height	−0.0038**		
	(c)	Weight-for-height	−0.0189$^{\text{n.s.}}$		
1.7	(a)	MUAC	−0.0376**	221.30	49.2
	(b)	Height	−0.0035**		
	(c)	Height-for-age	−0.0259*		
1.8	(a)	MUAC	−0.0427**	218.65	47.5
	(b)	Height	−0.0456**		
	(c)	Head circumference	0.0063[1]		

$^{\text{n.s.}}$ not significant.
* $P < 0.05$; ** $P < 0.01$.
[1] $P = 0.159$.

Table 4. *Linear regression models describing the relationship between weight-for-height, weight-for-age, MUAC, age and height.*

Model 1 – dependent variable: MUAC-for-age (%)

	Regression coefficient	*Standard error*
MUAC (mm)	0.620**	0.002
Age (months)	−0.181**	0.001
Constant	2.584**	0.225

Model 2 – dependent variable: weight-for-age (%)

	Regression coefficient	*Standard error*
MUAC (mm)	0.744**	0.058
Age (months)	−0.139**	0.005
Constant	−15.53**	0.785

Model 3 – dependent variable: weight-for-height (%)

	Regression coefficient	*Standard error*
MUAC (mm)	0.572**	0.045
Height (mm)	−0.097**	0.005
Constant	21.24**	0.551

** $P < 0.001$.

Table 5. *Comparison of different logistic regression models for the estimation of the risk of dying with weight, height, age, MUAC and head circumference as predictors.*

Predictors ($x_1, x_2, \ldots x_k$)			β	*log likelihood statistic*	*% of dead children in highest risk fifth*
2.1	(a)	Weight	−0.2831**	189.44	41.9
2.2	(a)	Weight	−0.4370**	208.35	44.5
	(b)	Age	0.0344**		
2.3	(a)	Weight	−0.4809**	200.02	44.5
	(b)	Height	0.0055**		
2.4	(a)	Weight	−0.1670**	219.50	47.8
	(b)	MUAC	−0.0321**		
2.5	(a)	Weight	−0.2529**	221.70	49.8
	(b)	MUAC	−0.0261**		
	(c)	Age	0.0144$^{\text{n.s.}}$		
2.6	(a)	Weight	−0.1659$^{\text{n.s.}}$	219.51	48.5
	(b)	MUAC	−0.0322**		
	(c)	Height	−0.0048$^{\text{n.s.}}$		
2.7	(a)	Weight	−0.1657**	221.28	49.8
	(b)	MUAC	−0.0258**		
	(c)	Weight-for-age	−0.0098$^{\text{n.s.}}$		
2.8	(a)	Weight	−0.1677**	219.62	49.2
	(b)	MUAC	−0.0305**		
	(c)	Weight-for-height	−0.0032$^{\text{n.s.}}$		
2.9	(a)	Weight	−0.1723**	225.32	48.8
	(b)	MUAC	−0.0274**		
	(c)	Height-for-age	−0.0289*		
2.10	(a)	Weight	−0.2312**	222.87	49.2
	(b)	MUAC	−0.0305**		
	(c)	Head circumference	0.0083[1]		

$^{\text{n.s.}}$ not significant.
* $P < 0.05$; ** $P < 0.01$.
[1] $P = 0.066$.

is also closely related to the risk of dying. These models are presented in Table 5. Their values were not compared statistically with models based on MUAC presented in Table 3 since they do not use the same subsets of variables.

For a given weight, olde or taller children had a higher risk of dying (models 2.1 to 2.3, Table 5). This finding is consistent with the standard hypothesis since, almost by definition, for a given weight, older and taller children have a lower weight-for-age or a lower weight-for-height (Table 6, models 1 and 2). These models, however, are also consistent with the muscle mass hypothesis: multiple linear regressions show that for a given weight, older or taller children had a lower MUAC (Table 6, models 3 and 4), which suggest that they also have a lower muscle mass.

When weight and MUAC are introduced in a model, height and age were no more significantly related to survival (models 2.4, 2.5, 2.6, Table 5). This also suggests that the relation between weight, MUAC, height and survival is unlikely to be due to the confounding effect of age.

A comparison of models 2.4, 2.7 and 2.8 (Table 5) also suggests that the rela-

Table 6. *Linear regression models describing the relationship between weight-for-age, weight-for-height, MUAC, weight, age and height.*

(a) Dependent variable: weight-for-age (%)

		Regression coefficient	*Standard error*
Model 1:	Weight (kg)	7.022**	0.022
	Age (months)	−1.122**	0.005
	Constant	40.31**	0.155

(b) Dependent variable: weight-for-height (%)

		Regression coefficient	*Standard error*
Model 2:	Weight (kg)	7.913**	0.023
	Height (mm)	−1.798**	0.006
	Constant	157.2**	0.305

(c) Dependent variable: MUAC (mm)

		Regression coefficient	*Standard error*
Model 3:	Weight (kg)	5.442**	0.046
	Age (months)	−0.601**	0.009
	Constant	98.9**	0.321
Model 4:	Weight (kg)	7.965**	0.067
	Height (mm)	−1.453**	0.018
	Constant	175.2**	0.875

** $P < 0.001$.

tionship between nutritional status (as assessed by weight-for-age and weight-for-height) and risk of dying could be explained by its relations with weight and MUAC. Height-for-age, however, seemed to be independently related to child survival (model 2.9, Table 5).

In an attempt to improve the assessment of risk of dying, the triceps skinfold thickness and head circumference were added as predictors. Skinfold thickness, or estimates of muscle based on the correction of MUAC for skinfold thickness (Jelliffe, 1966; Frisancho, 1981) did not significantly improve the prediction given by models already including MUAC. Head circumference consistently had a positive coefficient which almost reached statistical significance in one model, suggesting that the risk of dying for a given weight, MUAC or height may be greater for children with a larger head circumference (model 1.7, Table 3 and model 2.10, Table 5).

Discussion

In this study, anthropometric measures directly related to body size such as weight, height and MUAC were found to be more closely related to child survival than any nutritional indices derived from them. Comparison of different models describing the relationship between different anthropometric indices and survival suggest that survival is related to a measure of body size which increases with age faster than MUAC but more slowly than weight. This finding does not seem to be due to a confounding effect of age. The lack of statistical significance of age in the models including several measures related to muscle mass even suggests that the general decline of mortality with increasing age observed in this age range can be explained in terms of muscle mass growth. In this population, however, mortality had a peak between 18 and 29 months (presumably due to cessation of breast-feeding) which could not be explained in terms of muscle mass variations (results not shown here).

Models using anthropometric measures to estimate the risk of dying showed close similarities with those used to estimate muscle mass: the better chance of survival observed for a given MUAC in taller children (Table 3) is reminiscent of earlier studies which showed, by measures of creatinine excretion, that for a given MUAC taller children have a higher muscle mass (Trowbridge, Hiner & Robertson, 1982). Models showing that, for a given weight, taller (or older) children were at greater risk of dying (Table 5) are also consistent with the muscle mass hypothesis since linear regression showed that these children also had a lower MUAC (Table 6), and presumably a lower muscle mass.

On the other hand, the standard hypothesis is incompatible with the observed relations between MUAC, height, age and survival, showing that, for a given MUAC, older or taller children had a lower risk of dying (Table 3, models 1.2 and 1.3). The same type of relation was found previously in rural Bangladesh (Briend & Zimicki, 1986). This previous study, however, had a lower sample size and the relation between age, height and survival, when MUAC was already taken into account, was not statistically significant. Another study from rural Bangladesh also showed that for a given MUAC, children with the highest height-for-age had a better chance of survival (Alam, Wojtyniak & Rahaman, 1989), which suggests the same type of relationship between MUAC, height and survival. As shown in Table 4, for a given MUAC, older children have a lower weight-for-age and taller children have a lower weight-for-height. This relation was observed before and was even used to propose MUAC corrected for age or for height to quickly estimate weight-for-age or weight-for-height (Arnold, 1969). The conclusion from these findings (models 1.2 and 1.3, Table 3 and models 3 and 4, Table 4) taken together is that for a given MUAC, children with the lowest risk of dying have the lowest weight-for-age or the lowest weight-for-height, which is clearly inconsistent with the standard hypothesis. This suggests that the muscle mass hypothesis, which is compatible with all our results, is more likely than the standard hypothesis.

The positive coefficients of head circumference found in logistic regression models suggest that for a given muscle mass children with a larger head had a greater risk of dying. This is also consistent with the muscle mass hypothesis. The lack of statistical significance of these coefficients indicates, however, that including head circumference in screening schemes, as previously proposed (Kanawati & McLaren, 1970), is not useful.

Including skinfold thickness as predictor did not improve the assessment of the risk of dying. This is consistent with the hypothesis that the association between MUAC and survival is mainly related to the contribution of muscle. Triceps skinfold thickness, however, is difficult to measure and this may explain its lack of significance in logistic models. In any case, these results suggest that skinfold thickness is not useful for identifying children with a high risk of dying.

Although our data are consistent with the muscle mass hypothesis as stated in the introduction, and make it more likely than the standard hypothesis, our findings should not be regarded as proving our initial hypothesis. Anthropometric indicators of body size associated with survival are influenced also by body fat. Muscle is not only a reserve of amino acids to be converted into glucose for the brain, but has a complex metabolic role and represents also a reserve of other amino acids and of minerals which are important in terms of survival. Critical reexamination of past studies on the physiology of human starvation and of experimental animal studies on malnutrition, beyond the scope of this study, is needed to give a precise physiological interpretation to our findings.

The greater mortality observed in children with a low weight-for-age and low weight-for-height could be explained entirely by measures related to muscle mass. In contrast, a low height-for-age (or stunting) showed an independent association with the risk of dying which could not be explained in terms of muscle mass. There is no straightforward interpretation for this second observation but it may be due to a protein or mineral deficiency related both to stunting (Golden, 1985) and risk of dying. The almost identical numbers of children classified in the top risk fifth in models with and without height-for-age (Tables 3 and 5) show however that the importance of stunting to determine child survival was minimal compared with that of muscle mass.

When a child loses weight, he is most likely to change his body composition since he loses muscle first (Viteri, 1981). Hence, the muscle mass hypothesis would explain why, for the same level of weight-for-age, children who lost weight recently have a higher risk of dying compared to other children (Briend & Bari, 1989). Variations of the ratio between muscle mass and brain mass due to a change in body composition related to weight loss, however, are likely to be minor compared to those due to inter-individual differences in muscle mass. This could explain why assessment of weight gain has a poor screening value compared to attained weight-for-age for recognizing children with a high risk of dying (Briend & Bari, 1989).

In practical terms, this analysis suggests that nutritional indices based on comparisons with growth standards may not be the best means of identifying children with a high risk of dying. Screening schemes based on weight gain are not likely to be highly effective either. Young and small children may be more at risk than suggested by the value of all these indicators. Anthropometric measures, not corrected for age or for height, but combined together to give an estimate of muscle mass, may be more useful.

At all specificity levels, MUAC, without correction for age or height, is substantially better than classical nutritional indices based on comparison with growth standards to assess the risk of dying. Measuring and examining the arm of a malnourished child to assess his muscle status should be considered as an important step of the clinical examination. It should be preferred to more complex screening schemes for recognizing high-risk children.

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