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The effects of malnutrition on child mortality in developing countries

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Conventional methods of classifying causes of death suggest that about 70% of the deaths of children (aged 0–4 years) worldwide are due to diarrhoeal illness, acute respiratory infection, malaria, and immunizable diseases. The role of malnutrition in child mortality is not revealed by these conventional methods, despite the long-standing recognition of the synergism between malnutrition and infectious diseases. This paper describes a recently-developed epidemiological method to estimate the percentage of child deaths (aged 6–59 months) which could be attributed to the potentiating effects of malnutrition in infectious disease. The results from 53 developing countries with nationally representative data on child weight-for-age indicate that 56% of child deaths were attributable to malnutrition's potentiating effects, and 83% of these were attributable to mild-to-moderate as opposed to severe malnutrition. For individual countries, malnutrition's total potentiating effects on mortality ranged from 13% to 66%, with at least three-quarters of this arising from mild-to-moderate malnutrition in each case.

These results show that malnutrition has a far more powerful impact on child mortality than is generally appreciated, and suggest that strategies involving only the screening and treatment of the severely malnourished will do little to address this impact. The methodology provided in this paper makes it possible to estimate the effects of malnutrition on child mortality in any population for which prevalence data exist.

According to conventional methods of classifying causes of death, an estimated 70% of the deaths of children (aged 0–4 years) worldwide are due to diarrhoeal illness, acute respiratory infection, malaria and immunizable diseases (*1*). These methods do not identify malnutrition as a major cause of death in developing countries, despite its high prevalence and despite the long-recognized synergism between malnutrition and infection in child mortality (*2*). Infectious diseases represent the immediate and more obvious cause of death, while the role of malnutrition is only readily apparent when it is severe enough to cause clinical manifestations. Severe malnutrition is often classified under "nutritional deficiencies", and typically accounts for 1–5% of deaths in hospital-based mortality statistics from developing countries (*1*). The object of this paper is (i) to estimate the percentage of child deaths attributable to the potentiating effects of malnutrition on disease, using epidemiological (rather than clinical) methods which are capable of capturing the effects of mild-to-moderate as well as severe malnutrition, and (ii) to describe a simple but reliable methodology to make these estimates for specific countries, communities or population groups.

Methods

The methodology described below builds upon earlier work which provided epidemiological confirmation that the malnutrition–infection synergism observed clinically and in biomedical studies does indeed have a multiplicative impact on mortality at the population level (*3*). These findings have since been extended to permit estimation of malnutrition's quantitative impact on child mortality in specific populations. The development and testing of this methodology have been described in detail (*4*) and are only summarized here. In addition, a review of the literature has been published (*5*) which addresses questions of confounding by the child's age and socioeconomic factors, intercurrent morbidity, variation in length of follow-up, the relative importance of weight change versus attained weight, and other factors. This review supports the assump-

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tions made here, to the effect that the relationship between low weight-for-age and mortality is not simply a function of confounding by these factors. Moreover, variation in study designs, methodologies and measurement error would be expected to produce variations in the slope of mortality on weight-for-age across studies (rather than the homogeneity in slopes described below). Thus, the existence of methodological differences across studies cannot explain the consistency in the malnutrition–mortality relationship which is described below.

The cornerstone of the methodology is based on the results of eight community-based, prospective studies of the relationship between anthropometry and child mortality in developing countries. These eight studies were chosen from a larger number, reviewed elsewhere (*5*), because they used comparable methods for measuring and describing child nutritional status. They represent samples of children (aged 6–59 months) from the rural areas of Bangladesh, India, Indonesia, Malawi, Papua New Guinea, and the United Republic of Tanzania; when properly weighted by sample sizes they demonstrate remarkable consistency in the relative risk of mortality in relation to the child's weight-for-age.[a] These studies suggest that the risk of mortality increases at a compounded rate of 5.9% (±0.8% standard error) for each percentage point decline in weight-for-age below the reference point of 90% weight-for-age. The equivalent rate in *z*-scores is 5.5% ± 0.8 for each decrease of 0.1 *z*-score units below –1. This translates into relative risks of 8.4 for severe malnutrition (defined as <60% of reference or median weight-for-age), 4.6 for moderate malnutrition (60–69% of median), and 2.5 for mild malnutrition (70–79% of median). The standard errors in these estimates are 2.1, 0.9 and 0.3, respectively. Formal statistical tests (regression of log mortality on weight-for-age, weighted by sample size and testing for interactions between weight-for-age and study) reveal that there is no significant variation in the response of mortality to malnutrition across these eight studies, despite significant differences in disease ecology, prevalence of stunting (low height-for-age) and wasting (low weight-for-height), and age range of the study children. The above relative risk estimates can therefore be applied to diverse populations to describe the risk of death as a function of child weight-for-age. Further discussion and testing of the assumptions inherent in applying these parameter estimates to diverse populations can be found in the original methodological paper (*4*).

Using the aforementioned relative risk estimates, the standard epidemiological statistic of population-attributable risk (PAR) is used to estimate the percentage of child deaths attributable to malnutrition's potentiating impact on infectious disease. The PAR statistic combines information on the strength of the association between low weight-for-age and mortality and the prevalence of low weight-for-age, to estimate the percentage of total deaths statistically associated with low weight-for-age. Causal inferences concerning malnutrition's role cannot be based on the PAR alone, but derive from other types of biological, clinical and epidemiological evidence concerning these relationships.

The formula for PAR (*6*) is:

$$\text{PAR} = \frac{\text{Deaths related to malnutrition}}{\text{Total deaths}} = \frac{\text{Prev} \times (\text{RR}-1)}{1 + [\text{Prev} \times (\text{RR}-1)]} \quad (1)$$

where Prev is the prevalence of malnutrition and RR is the ratio of mortality among the malnourished to mortality among the non-malnourished (i.e., relative risk).

When information is available on the distribution of malnutrition across severe, moderate and mild grades, the above formula can be extended as follows:

$$\text{PAR} = \frac{\sum(\text{Prev}_i \times (\text{RR}_i-1))}{1 + \sum [\text{Prev}_i \times (\text{RR}_i-1)]} \quad (2)$$

Where Prev_i is the prevalence of malnutrition in each of the three grades (severe, moderate and mild), RR_i is the corresponding relative risk of mortality within each grade, and $\sum$ represents summation across all grades of malnutrition. As implied by this formula, the PAR attributable to all grades of malnutrition can be estimated directly from the prevalence of low weight-for-age, using the relative risk estimates of 8.4, 4.6 and 2.5 for severe, moderate and mild malnutrition, as described above. The testing of alternative methodologies for estimating PAR (*4*) reveals greater precision when multiple grades of malnutrition are used (equation 2) rather than a single grade (equation 1). Accordingly, the international prevalence data used in this paper is based on the compilation by UNICEF (*7*), which provides the

[a] Note that two of the eight studies, including that by Chen et al.(*8*), appear to have slopes that deviate from the others, but these deviations are not statistically significant when variation in sample sizes is taken into account through use of a weighted regression. This exception, along with the two exceptions from Zaire, are discussed elsewhere (*4, 5*).

prevalence of severe (<–3 z-scores) and moderate (–2 to –3 z-scores) underweight in 53 developing countries. This publication also provides an overall weighted average prevalence, based on these same countries. All of the prevalence estimates in that source are derived from nationally representative sample surveys of children aged 0–59 months. These prevalence estimates are slightly lower than the true values for children aged 6–59 months, upon whom the relative risk estimates are based and to whom these results pertain. The z-score-based prevalences from the UNICEF (7) were converted to the percentage of median prevalences required in equation 2, using the procedure described in Pelletier et al. (4). The results of the PAR calculations are presented in terms of the total PAR (arising from all three grades of malnutrition combined) and the percentage of total PAR, which is accounted for by mild-to-moderate manutrition (MMM) (60–79% of median weight-for-age).

Results

Fig. 1 shows the estimates of total PAR and the percentage attributable to MMM for the 53 countries and the weighted average of all 53 countries (exact values shown in Table 1). Countries are ordered from lowest to highest, based on the value for total PAR. The percentage of child deaths attributable to the potentiating effects of malnutrition ranges from a low of 13 in Paraguay to a high of 67 in India, with a weighted average of 56%. The median for these 53 countries, which is not heavily influenced by India, is 38%. The percentage of total PAR that is attributable to mild-to-moderate malnutrition ranges from a low of 73–74% in Bangladesh and India to a high of 100% in those countries with very low malnutrition prevalences, with a weighted average of 83%. Thus, even in those countries with the highest prevalence of severe malnutrition, at least three-quarters of all the malnutrition-related deaths are attributable to mild-to-moderate malnutrition rather than severe.

Fig. 2 shows that there is a close curvilinear relationship between total PAR in these 53 countries and the total prevalence of low weight-for-age (i.e., weight-for-age <80% of median). This relationship is well described by the following quadratic equation:

$$\text{Total PAR} = (\text{Prev80} \times 1.42) + (\text{Prev80}^2 \times -0.0075) + 0.87 \qquad (3)$$

where Prev80 is the percentage of children less than 80% weight-for-age. This equation has a high R-squared (99.1%) and high precision of prediction (SE of the estimate = 1.37). In addition, with a standard error of 0.76, the intercept (0.87) essentially passes through zero. This is as expected because total PAR should equal zero when the prevalence of malnutrition (Prev80) is zero. Therefore, this equation represents a simple approach for estimating total

Fig. 1. **The total population-attributable risk (PAR) for child deaths due to the potentiating effects of malnutrition on infectious diseases but also related to malnutrition, which is severe or moderate-to-mild (MMM).**

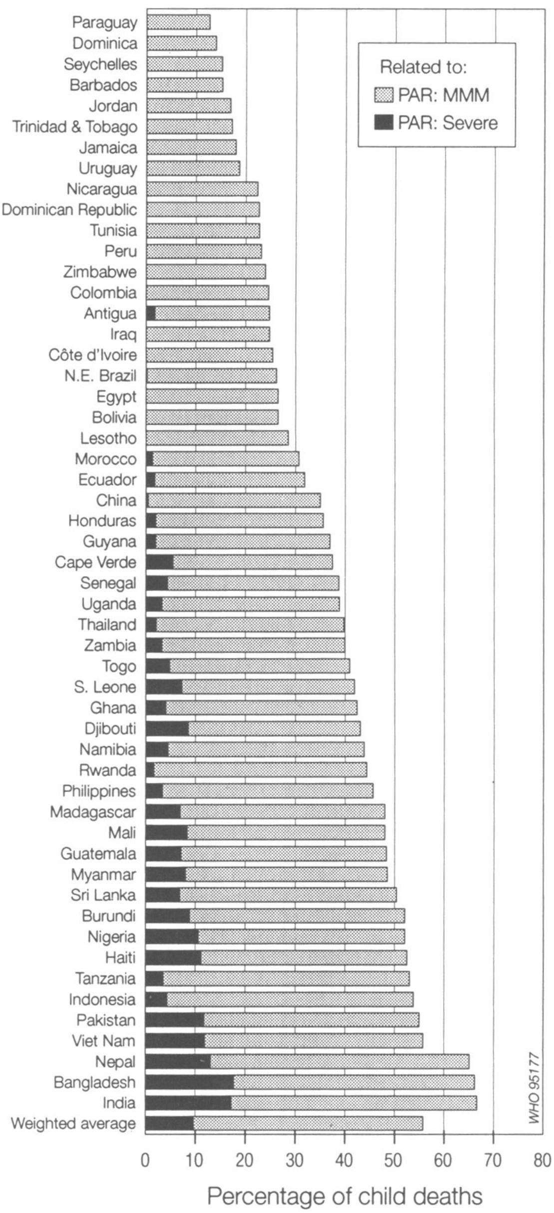


Table 1: **Percentage of child deaths attributable to the potentiating effects of malnutrition (total PAR) and the proportion of this that is related to mild-to-moderate malnutrition (MMM) in 53 countries or areas**

Country or area	Total PAR (%)	Related to MMM (%)
Paraguay	13	100
Dominica	14	100
Seychelles	15	100
Barbados	15	100
Jordan	17	100
Trinidad & Tobago	17	100
Jamaica	18	100
Uruguay	19	100
Nicaragua	23	100
Dominican Republic	23	100
Tunisia	23	100
Peru	23	100
Zimbabwe	24	100
Colombia	25	100
Antigua	25	92
Iraq	25	100
Côte d'Ivoire	26	100
N.E. Brazil	26	99
Egypt	27	100
Bolivia	27	100
Lesotho	29	100
Morocco	31	95
Ecuador	32	94
China	35	98
Honduras	36	94
Guyana	37	94
Cape Verde	38	85
Senegal	39	89
Uganda	39	91
Thailand	40	94
Zambia	40	91
Togo	41	88
Sierra Leone	42	83
Ghana	42	90
Djibouti	43	80
Namibia	44	90
Rwanda	44	96
Philippines	46	93
Madagascar	48	85
Mali	48	82
Guatemala	48	83
Myanmar	49	83
Sri Lanka	50	86
Burundi	52	83
Nigeria	52	80
Haiti	53	79
Tanzania	53	93
Indonesia	54	92
Pakistan	55	79
Viet Nam	56	78
Nepal	65	80
Bangladesh	66	73
India	67	74
Weighted average	56	83

PAR in any population for which the prevalence of low weight-for-age has been estimated.

Fig. 3 shows a similar strong relationship between the percentage of total PAR attributable to mild-to-moderate malnutrition and the prevalence of severe malnutrition (weight-for-age <60%). The equation describing this relationship is:

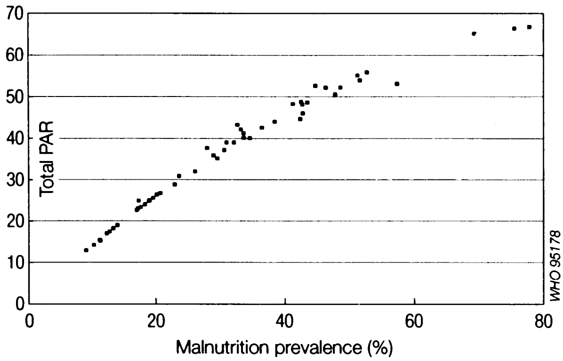
$$\text{Percent MMM} = (\text{Prev60} \times -9.02) + \text{Prev60}^2 \times 0.8058) + 99.2 \quad (4)$$

where Prev60 is the percentage of children less than 60% of median weight-for-age. The R-squared value for this equation is 95.0% and the SEE of 1.84 reveals high predictive precision. In addition, the intercept of 99.2 conforms to the expectation that when severe malnutrition (Prev60) is zero, then the Percent MMM is essentially 100%. Therefore, this equation can be used in conjunction with equation 3 to estimate the percentage of total PAR which is attributable to mild-to-moderate malnutrition.

Discussion

These results add greatly to our understanding of the relationship between child malnutrition and mortality. First, they reveal that malnutrition, by virtue of its synergistic relationship with infectious disease, has a powerful impact on child mortality (total PAR = 56%) and one that is much larger than suggested by the category of "nutritional deficiencies" in most routine reporting systems. Second, they reveal that the vast majority of malnutrition-related deaths (83%) are attributable to mild-to-moderate, rather than severe, malnutrition. This is contrary to the widespread perception that mortality is elevated only among the severely malnourished, a perception that arose in part because one of the earliest studies of this relationship found no elevated risk above 65% weight-for-age (*8*). This result has generally not been confirmed in community-based studies since that time, including several conducted in the same areas of Bangladesh (*5*). One exception is a recent report

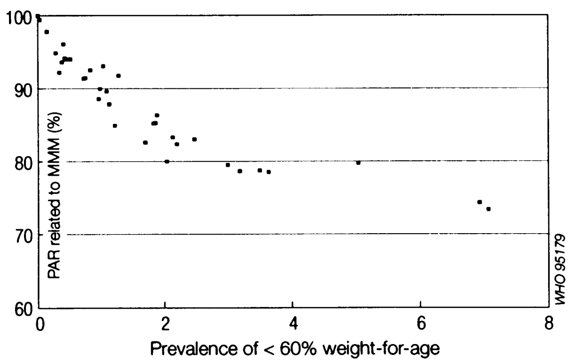
Fig. 2. **Data from 53 developing countries on the total population-attributable risk (PAR) for child deaths in relation to the prevalence of malnutrition (<80% median weight-for-age).**



from Zaire (*9*), which the authors hypothesize is attributable to the exceptional importance of malaria as a cause of morbidity and mortality in that setting.

Most studies, to date, have quantified mortality risks only as relative risks and other parameters which do not take account of the proportions of children in different grades of malnutrition. The present finding, that 83% of all malnutrition-related deaths are attributable to the potentiating effects of mild-to-moderate malnutrition, clearly suggests that intervention strategies that rely heavily or exclusively on screening and treating only the severely malnourished will fail to address the major source of the malnutrition–infection synergism. Equations 3 and 4 make it possible to estimate the effects of malnutrition (and mild-to-moderate malnutrition) on child mortality in any population for which prevalence

Fig. 3. **Data from 53 developing countries on the population-attributable risk (PAR) associated with mild-to-moderate malnutrition (MMM) in relation to severe malnutrition (<60% median weight-for-age).**



data exist.[b] The PAR methodology used here rests on the empirical observation, based on eight prospective studies, that the quantitative impact of malnutrition on child mortality exhibits little variation across populations with different disease ecology. This observation suggests that the malnutrition–infection synergism may have mortality consequences for many forms of morbidity and is not restricted to the case of diarrhoeal illness and measles (*10*). The aforementioned study from Zaire (*9*) suggests that malaria may be an exception, when it is the dominant cause of morbidity and mortality, but this finding requires further epidemiological and clinical confirmation.

The quantitative estimates provided here are remarkably similar to those found by the Pan American Health Organization (PAHO) in the Inter-American Investigation of Mortality in Childhood, conducted in 15 countries (*11*). This study, using direct clinical, autopsy and family interview methods to ascertain the primary and associated causes of death for each individual, found that malnutrition was implicated in 56% of all deaths among children aged 1–4 years; of these, malnutrition was identified as the primary cause of death in 15% of cases (indicating severe forms) and as an associated cause of death in 85% of cases (indicating less severe forms). Thus, the estimates arising from the anthropometry-based method in the present paper are of the same magnitude as those found using direct methods for ascertaining the cause of death. They are also similar to PAR estimates by Schroeder & Brown (*12*) who used five of the eight studies used here, but employed different assumptions, methods and data sources.

The malnutrition–infection synergism appears to be a physiological vicious cycle and has been recognized as important for public health policy and practice for over two decades (*2*). Similarly, the findings by the Inter-American Investigation concerning its quantitative effects on mortality at the population level were known twenty years ago, and led PAHO to give high priority to reducing malnutrition as part of programmes to reduce mortality (*11*). More recently, it has been confirmed that malnutrition has potentiating effects on mortality at the population level (*3*), precisely as would be predicted from the vicious-cycle concept. An important contribution of the present findings is to provide quantitative estimates of malnutrition's effects for a broader set of regions and countries of the world, in order to

[b] It should be noted that the accuracy of PAR estimates, derived from equations 3 and 4, depends on the accuracy with which the prevalence of low weight-for-age was estimated, in addition to the errors inherent in the equations themselves (*4*).

encourage a re-examination of the priority given to nutrition in child survival strategies and in related resource allocation decisions. It is important to note that significant reductions in child mortality have been and can be achieved through selective health interventions, even in the face of persisting malnutrition (*13, 14*). The present results do not contradict that fact. However, they do imply that malnutrition strongly exacerbates the burden of life-threatening diseases in developing countries, increases the associated health care costs, and increases the mortality risk for individuals not adequately covered by the health care system. Our findings suggest that these concerns could be significantly reduced through enhanced efforts to reduce malnutrition of all grades, and not the severe cases only. Thus, there are benefits in cost-effectiveness, in addition to the humanitarian and ethical reasons, for ensuring that adequate attention is paid to nutrition in health and development policies.

Résumé

Les effets de la malnutrition sur la mortalité infantile dans les pays en développement

Les méthodes habituelles de classification des causes de décès conduisent à penser qu'environ 70% des décès d'enfants de 0 à 4 ans dans le monde sont dus à la diarrhée, aux infections respiratoires, au paludisme et aux maladies évitables par la vaccination. Ces méthodes ne mettent pas en évidence le rôle de la malnutrition, bien que l'on sache depuis longtemps qu'il existe une synergie entre la malnutrition et les maladies infectieuses. Le présent article décrit une méthode épidémiologique récemment mise au point pour estimer le pourcentage de décès qui pourraient être attribués aux effets potentialisateurs de la malnutrition sur les maladies infectieuses chez les enfants âgés de 6 à 59 mois. Les données recueillies dans 53 pays en développement où il existe des statistiques nationales sur le poids des enfants en fonction de l'âge montrent que 56% des décès d'enfants sont attribuables aux effets potentialisateurs de la malnutrition et que dans 83% des cas il s'agit d'une malnutrition légère à modérée, et non d'une malnutrition grave. Selon les pays, les effets potentialisateurs de la malnutrition varient entre 13% et 66%, une forme de malnutrition légère à modérée étant en cause dans au moins trois cas sur quatre.

Ces résultats montrent que la malnutrition a une incidence beaucoup plus importante sur la mortalité infantile qu'on ne le croit généralement. Ils donnent aussi à penser que des stratégies visant seulement à dépister et à traiter les cas les plus graves ne contribueront guère à résoudre le problème. La méthodologie présentée dans cet article permet d'estimer les effets de la malnutrition sur la mortalité infantile dans toute population pour laquelle il existe des données sur la prévalence de ce phénomène.

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