TABLE 7

Interaction between child's age and anthropometric indicators in relation to subsequent mortality, Indonesia (study 8)[1,2]

Indicators	Child's age in months 0–11	12–23	24–35	36–59
Height-for-age				
<90%				
Rate	173.9	149.7	85.1	18.8
N	4/23	28/187	20/235	13/693
RR(age)	9.25	7.96	4.53	1.00
RR(HA)	6.06	11.01	7.15	1.55
90–94%				
Rate	84.8	46.8	21.9	9.1
N	14/110	20/285	8/244	6/440
RR(age)	9.32	5.14	2.41	1.00
RR(HA)	2.95	3.44	1.84	.75
≥95%				
Rate	28.7	13.76	11.9	12.1
N	26/605	4/196	3/168	5/275
RR(age)	2.37	1.12	.98	1.00
RR(HA)	1.00	1.00	1.00	1.00
PAR(HA)	21.6%	67.1%	63.2%	19.2%
Weight-for-height				
<90%				
Rate	118.5	108.8	78.2	23.3
N	16/135	26/239	14/179	5/2158
RR(age)	5.09	4.67	3.36	1.00
RR(WH)	3.82	2.69	3.23	2.20
≥90%				
Rate	31.0	40.4	24.2	10.6
N	28/603	26/429	14/179	5/215
RR(age)	2.92	3.81	2.28	1.00
RR(WH)	1.00	1.00	1.00	1.00
PAR(WH)	26.8%	31.4%	31.2%	11.3%

[1] Calculated from Katz et al. (1989).

[2] Rate = mortality rate per 1,000 children; N = number of deaths divided by number of children; RR(age) = relative risk for age, where the reference group is 36–59 months old; RR(HA) = relative risk for height-for-age where the reference group is ≥95% height-for-age; PAR(HA) = population attributable risk for height-for-age where mal is ≥95% height-for-age; RR(WH) = relative risk for weight--height where the reference group is ≥90% weight-for-height; AR(WH) = population attributable risk for weight-for-height where normal is ≥90% weight-for-height.

pretation is made difficult by the use of different indicators, cutoff points and age ranges in various studies, some general conclusions are suggested by these data. The major caution is that the conclusions should be restricted to within-study comparison of relative risks, rather than between-study comparisons. The table shows that mild deficits of WA are not associated with elevated mortality among older children, though they are associated in younger children.

Moderate and severe deficits have elevated risks in all age groups. This is consistent with the knowledge that much of the weight deficit in older children is due to height deficits that accumulated earlier and may not pose any current danger to the child. The results for WH reveal that moderate and severe deficits are associated with modest elevations in mortality risk through 23 months of age, as do moderate deficits among older children (>23 months). However, in both studies, there is a marked elevation in risk among older children when the deficit is severe. The relative risks among older children (>12 months) are similar in magnitude to those found for AC/HT in Bangladesh, which represents an alternative indicator of wasting and also corrects for child's height. These results sug-

TABLE 8

Interaction between child's age and anthropometric indicators in relation to subsequent mortality, SW Uganda (study 17)[1,2]

Indicators (Z-Scores)	Child's age in months 0–5	6–11	12–23	24+
Height-for-age				
< −3				
Rate	300.0	74.1	41.7	37.7
N	3/10	2/27	5/120	13/345
RR(age)	7.96	1.97	1.11	1.00
RR(HA)	6.26	2.09	3.04	2.31
−3−−2.01				
Rate	142.9	40.5	21.4	13.9
N	4/28	3/74	4/187	6/432
RR(age)	10.28	2.91	1.57	1.00
RR(HA)	2.98	1.15	1.56	.85
> −2.0				
Rate	47.9	35.4	13.7	16.3
N	15/313	11/311	7/511	23/1410
RR(age)	2.94	2.17	.84	1.00
RR(HA)	1.00	1.00	1.00	1.00
PAR(HA)	24%	9%	30%	15%
Weight-for-height				
< −1.5				
Rate	166.7	86.2	42.4	76.0
N	3/18	5/58	5/118	12/158
RR(age)	2.19	1.13	.56	1.00
RR(WH)	3.06	3.02	2.64	5.47
−1.5−−1.01				
Rate	95.2	76.9	13.0	17.5
N	2/21	3/39	1/77	4/228
RR(age)	5.44	4.39	.74	1.00
RR(WH)	1.75	2.69	.81	1.26
> −1.0				
Rate	54.5	28.6	16.1	13.9
N	17/312	9/315	10/623	25/1801
RR(age)	3.92	2.06	1.16	1.00
RR(WH)	1.00	1.00	1.00	1.00
PAR(WH)	13%	31%	18%	26%

[1] Calculated from Vella et al. (1994).

[2] Rate = mortality rate per 1000 children; N = number of deaths divided by number of children; RR(age) = relative risk for age, where the reference group is 36–59 months old; RR(HA) = relative risk for height-for-age where the reference group is ≥95% height-for-age; PAR(HA) = population attributable risk for height-for-age where normal is ≥95% height-for-age; RR(WH) = relative risk for weight-for-height where the reference group is ≥90% weight-for-height; PAR(WH) = population attributable risk for weight-for-height where normal is ≥90% weight-for-height.

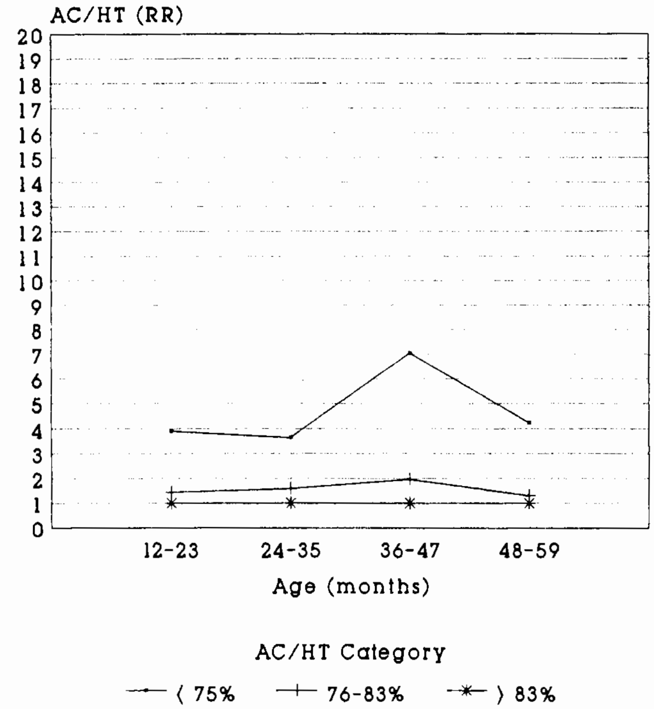

FIGURE 11 Matlab, Bangladesh (study 2a): relative risk of mortality according to child's age and AC/HT. Data from Sommer and Lowenstein (1975). AC/HT = arm circumference/height; RR = relative risk.

TABLE 9

Interaction between child's age and arm circumference in relation to subsequent mortality Bangladesh (study 2a)[1,2]

Arm circumference-for-height	Child's age in months			
	12–23	24–35	36–47	48–59
<75%				
Rate	118.6	136.4	177.4	60.6
N	7/59	9/66	11/62	4/66
RR(age)	1.96	2.25	2.93	1.00
RR(ACHT)	3.89	3.64	7.04	4.24
76–83%				
Rate	44.1	59.7	49.3	18.7
N	18/408	26/435	20/406	6/321
RR(age)	2.36	3.19	2.64	1.00
RR(ACHT)	1.45	1.59	1.96	1.31
≥83%				
Rate	30.5	37.5	25.2	14.3
N	15/492	19/507	13/515	6/420
RR(age)	2.13	2.62	1.76	1.00
RR(ACHT)	1.00	1.00	1.00	1.00
PAR(ACHT)	26.7%	30.0%	43.7%	27.9%

[1] Calculated from Sommer et al. (1975).

[2] Rate = mortality rate per 1000 children; N = number of deaths divided by number of children; RR(age) = relative risk for age, where the reference group is 48–59 months old; RR(ACHT) = relative risk for arm circumference-for-height (ACHT) where the reference group is ≥83% ACHT; PAR(ACHT) = population attributable risk for ACHT where normal is ≥83% ACHT.

gest that wasting (when defined with a common percent of median cutoff across all ages) is more strongly associated with mortality among older children than among younger children. Some of this may be due to the increase in variance with age, but the present analyses do not permit this to be quantified. Finally, these results reveal that mortality is elevated among those with moderate height deficits before 24 months of age, but much less so beyond that age, and that severe height deficits are associated with elevated mortality at all ages. The findings pertaining to HA at older ages confirm the interpretation related to WA, that moderate stunting poses no immediate threat to survival when it occurs among older children.

Gender effects. Considering the disproportionate number of studies coming from South Asia (Table 1) and the evidence for sex differences in dietary intake, nutritional status, health care and mortality in this part of the world (Abdullah and Wheeler 1985; Chen et al. 1981; Das Gupta 1987; Kielmann et al. 1978), it is surprising to find that only two studies have undertaken an explicit analysis of effect modification due to sex of the child (Cogill 1982). Several studies appeared from verbal descriptions in the text to have tested or controlled for main effects due to sex (all finding that gender does not account for the anthro-

TABLE 10

Interaction between child's age and arm circumference in relation to subsequent mortality, SW Uganda (study 17)

Arm circumference	Child's age in months			
	1–5	6–11	12–23	24+
cm				
<12.5				
Rate	106.2	90.9	71.4	200.0
N	12/113	4/44	3/42	6/30
RR(age)	.53	.45	.36	1.00
RR(AC)	2.39	3.60	5.13	13.33
12.5–13.4				
Rate	40.0	56.8	32.3	48.2
N	4/100	5/88	4/124	4/83
RR(age)	.83	1.18	.67	1.00
RR(AC)	.90	2.25	2.32	3.21
>13.5				
Rate	44.4	25.3	13.9	15.0
N	6/135	7/277	9/646	31/2066
RR(age)	2.96	1.69	.93	1.00
RR(AC)	1.00	1.00	1.00	1.00
PAR(AC)	30%	35%	29%	20%

[1] Calculated from Vella et al. (1994).

[2] Rate = mortality rate per 1000 children; N= number of deaths divided by number of children; RR(age) = relative risk for age, where the reference group is 48–59 months old; RR(AC) = relative risk for arm circumference where the reference group is ≥13.5 cms ACHT; PAR(AC) = population attributable risk for AC where normal is ≥13.5 cms AC. AC = arm circumference.

TABLE 11

Mortality rates, relative risks, and population attribute risks for weight-for-height and height-for-age, stratified by age of the child, Indonesia (Study 8)[1,2]

Age	Nutritional status[3]	Weight-for-height				Height-for-age			
		N	Rate	RR	PAR	N	Rate	RR	PAR
mo									
<12	Normal	28/603	31.0	1.0	—	26/605	28.7	1.0	—
	Moderate	14/116	80.5	2.8	12.9	14/110	84.8	3.2	14.0
	Severe	2/19	70.2	2.4	1.6	4/23	173.9	6.1	7.6
	Total				14.5				21.6
12–23	Normal	26/429	40.4	1.0	—	4/196	13.6	1.0	—
	Moderate	23/212	72.3	1.9	13.0	20/285	46.8	3.6	18.2
	Severe	3/27	74.1	1.9	1.7	28/187	149.7	11.0	48.9
	Total				14.7				67.1
24–35	Normal	17/468	24.2	1.0	—	3/168	11.9	1.0	—
	Moderate	10/164	40.7	1.7	8.7	8/244	21.9	1.9	7.9
	Severe	4/15	177.8	9.6	7.4	20/235	85.1	7.2	55.5
	Total				16.2				63.4
36–59	Normal	19/1193	10.6	1.0	—	5/275	12.1	1.0	—
	Moderate	2/201	6.6	0.6	0.0	6/440	9.1	0.7	0.0
	Severe	3/14	142.9	16.9	7.7	13/693	18.8	1.6	19.3
	Total				7.7				19.3
0–59	Normal	90/2693	22.4	1.0	—	38/1244	20.4	1.0	—
	Moderate	49/693	47.1	2.2	11.3	48/1079	29.7	1.5	6.6
	Severe	12/75	106.7	5.5	4.2	65/1138	38.1	1.9	20.1
	Total				15.5				26.7

[1] Calculated from Katz et al. (1989).
[2] N = number of deaths divided by number of children; Rate = deaths per 1000 children per year; RR = relative; risk; PAR = population attributable risk.
[3] Normal (Z > −1): weight-for-height (WH) > 90%; height-for-age (HA) > 95%; moderate (−1 > Z > −2): WH 80–89%; HA 90–94%; severe: (Z < −2); WH < 80%; HA < 90%.

pometry effect); however, they did not appear to have undertaken interaction analysis. This is unfortunate in light of the markedly different results which Cogill (1982) and Fauveau et al. (1992) obtained for males and females as described below.

The analysis by Cogill (1982) compared the performance of seven anthropometric indicators in predicting mortality within 2 years of measurement. **Table 13** shows these indicators, their normalized distance statistics (d_a)[13] and their ranks for males, females and sexes combined. The results shown here are very similar to those found with other criteria of indicator performance in Cogill's work. With the exception of WH-based indicators, which are low in both sexes, the mortality discrimination of all other indicators is greater among females than males, especially in the case of WA and HA. The results for combined sexes tend to be intermediate or to resemble those for females. The effect on the ranks is such that mortality is best discriminated by HA, AC and WA among females, and by arm circumference-for-height (ACHT), arm circumference-for-age (ACA) and AC in males. The two best discriminators among females (HA and WA) are ranked fourth and fifth among males.

The overall results by Cogill have since been confirmed by a study in the same area of Bangladesh (Fauveau et al. 1990). This study, which determined malnutrition based on visible wasting and recent weight loss just before death, found that the RR of death for girls is 1.8 times that for boys. The corresponding RR is 2.1 for deaths "due to wasting" and 2.6 for deaths due to wasting in combination with persistent diarrhea. Both sexes experienced an increase in mortality during the preharvest season, but this was especially marked for girls (i.e., the number of deaths per month increased from 2.3 to 4.4 for boys, and from 3.3 to 10.5 for girls).

In attempting to explain the gender differences in the anthropometry-mortality relationship, Cogill notes that females in the sample have a mortality rate that is twice that of males and significantly lower levels of nutritional status as reflected in anthropometric indicators. The latter is consistent with evidence of male preference in food allocation (in terms of quality and

[13] d_a is calculated for each indicator as the difference between the means of dead and surviving children, divided by the square root of the average variance of the indicator in dead and surviving children (Brownie et al. 1986).

TABLE 12

Summary of age-specific relative risks of mortality by indicator[1]

Study	Indicator	Severity	Age[a] 0–11	12–23	12–36	24+
Punjab[2] (study 7)	WA	Normal (>80%)	(19)	—	(3)	—
		Mild (70–79)	3.1	—	1.2	—
		Moderate (60–69)	4.5	—	2.8	—
		Severe (<60)	8.8	—	13.1	—
SW Uganda[2] (Study 17)	WA	Normal (>−1.5 Z)	(42)	(12)		(14)
		Mild-Mod (−1.5 to −2.5)	1.65	1.7		1.2
		Mod-Sev (<−2.5)	3.82	5.3		4.7
Indonesia[4] (Study 8)	WH	Normal (>90%)	(31)	(40)		(22)
		Moderate (80–89)	2.8	1.9		1.5
		Severe (<80)	2.4	1.9		11.1
SW Uganda[3] (Study 17)	WH	Normal (>−1 Z)	(45)	(16)		(14)
		Moderate (−1.5 to −1.0)	1.9	.8		1.3
		Severe (>−1.0)	2.4	2.6		5.5
Bangladesh[5] (Study 2a)	AC/HT	Normal (>83%)	—	(30)		(37)
		Moderate (76–83)	—	1.5		1.6
		Severe (<75)	—	3.9		3.6
Indonesia[4] (Study 8)	HA	Normal (>95%)	(29)	(14)		(18)
		Moderate (90–99)	3.0	3.4		1.1
		Severe (<90)	6.1	11.0		2.0
SW Uganda[3] (Study 17)	HA	Normal (>−2)	(42)	(14)		(16)
		Moderate (−2 to −3)	1.6	1.6		.8
		Severe (<−3)	3.2	3.0		2.3

[1] WA = weight-for-age; WH = weight-for-height; AC/HT = arm circumference/height; HA = height-for-age.
[2] Adapted from Kielmann and McCord (1978).
[3] Adapted from Vella et al. (1994).
[4] Adapted from Katz et al. (1989).
[5] Adapted from Sommer and Lowenstein 1975.
[a] Figures in parentheses are the mortality rates for the reference groups.

quantity) in this population (Chen et al. 1981). Yet, these observations alone are insufficient to explain why the relationship between these indicators and mortality is stronger *within* the female subsample as compared to males. Part of the answer may lie with the fact that, despite similar morbidity attack rates, female children are brought to free health facilities only 60% as often as males (Chen et al. 1981). Thus, greater utilization of curative health services by males may partially uncouple the linkage between nutritional status and mortality as compared to females. This is supported by more recent analysis of data from the same area of Bangladesh (Fauveau et al. 1991) and in South Asia in general (Basu 1989).

Morbidity. The existence of a synergistic relationship between malnutrition and infectious disease has been widely recognized for several decades (Scrimshaw et al. 1968). In the case of PEM the relationship is such that recurrent morbidity has a negative effect on nutritional status; poor nutritional status may, depending on the disease, increase either the incidence, severity and/or duration of morbidity; and the combination of poor nutritional status and morbidity increases the risk of death. The classic model of this interaction is with measles (Morley 1973), but the evidence relating malnutrition to immunocompetence suggests similar interactions with a variety of diseases (Chandra 1991; Martorell and Ho 1984).

Given these interactions it is not meaningful in any practical sense to attempt to separate the effects of nutritional status from those of morbidity as they relate to risk of mortality. This was discussed earlier with reference to Figure 5. Given the ubiquity of disease in developing countries only a very minor fraction of child deaths result directly and exclusively from malnutrition. Most deaths result from disease made worse by malnutrition.

As distinct from the above question, a number of investigators have raised the possibility that children with low weight-for-age (for instance) may appear to

TABLE 13

Normalized distance statistic and ranks for seven anthropometric indicators in Bangladeshi males, females and combined sexes (study 1d)[1]

Indicators	Normalized distance			Ranks		
	Males	Females	Combined	Males	Females	Combined
Height-for-age	0.2790	0.7306	0.5797	5	1	1
Weight-for-age	0.3644	0.6628	0.5793	4	2	3
Arm Circumference-for-age	0.4438	0.6156	0.5623	1	3	4
Arm Circumference	0.4180	0.5970	0.5886	3	4	2
Arm Circumference-for-height	0.4196	0.5320	0.5440	2	5	5
Weight/height^2	0.2657	0.2037	0.2936	6	6	6
Weight-for-height	0.1942	0.0540	0.1198	7	7	7

[1] Adapted with permission from Cogill (1982).

have an elevated risk of mortality simply because the disease that killed them resulted in acute weight loss during the weeks immediately preceding death. Thus, their low weight-for-age may be only secondary to the real cause of death and the entire association between WA and mortality may be due to statistical artefact.[14] The four studies bearing on these possibilities are reviewed below.

In their 1-year follow-up of children from Punjab, India, Kielmann and McCord (1978) recognized that the effect of low weight-for-age on subsequent mortality may be overestimated because concurrent infection is likely to decrease weight-for-age in the few weeks preceding death. Because children in that study had been weighed monthly, the investigators were able to minimize this effect by trying to confirm their overall results on a subsample. Specifically, they analyzed mortality in relation to the weight-for-age of each child as measured 2 months before death rather than the 1 month immediately preceding death. This eliminated 37 of the children (34%) from the analysis, representing those who died in the first month of the study and could not be assigned to a weight-for-age category.

The analysis by Kielmann and McCord shows that in each of the three age groups the relationship between weight-for-age and mortality is the same in the two samples. Thus, the authors concluded that the effect of concurrent illness on weight-for-age is unlikely to account for the association between the latter and mortality. It is possible that acute morbidity may affect weight-for-age for more than 1 month before death, thereby invalidating this approach for "controlling" these effects. However, the close correspondence between the controlled and uncontrolled results suggests that confounding of weight-for-age by intercurrent morbidity is unlikely to account for the association in its entirety. Moreover, if morbidity persists for more than 1 month, it is likely to have significant effects on nutritional status itself, not simply the weight-for-age proxy for nutritional status.

In a study from rural Bangladesh, Briend and Bari (1989b) used multivariate logistic regression to control for concurrent morbidity, while examining the association between severe weight-for-age and mortality of 0–36-month-olds. Children were classified as being above or below 60% WA and according to the presence or absence of diarrhea, respiratory infections, measles and edema. The mortality odds ratio for the WA variable was reduced from 14.7 (unadjusted) to 9.7 after adjusting for the presence/absence of these illnesses (with a 95% confidence interval of 5.7 to 16.6 for the adjusted ratio). Because there was no association between mortality and diarrhea in this sample (which the authors attribute to an intensive oral rehydration solution (ORS) program in the area), the association between mortality and WA is unaffected by diarrhea. This study therefore suggests that the incidence of concurrent morbidity does not account for all of the association between severely low WA and mortality. This may be because the study only controlled for the presence/absence of morbidity in the preceding mo, which does not fully account for the possible weight-depressing effects of morbidity.

Although the authors did not conceptualize it as such, another form of control over the confounding effects of morbidity was exercised in the studies by Briend and Bari (1989b) and Yambi (1988). These analyses were designed to compare indicators of weight change over the course of $\geq$1 mo to indicators of attained weight in the same mortality-prediction model, for the purpose of identifying the best indicator for screening purposes. However, this can also be conceptualized as an effort to distinguish the immediate weight-reducing effects of a current illness (as reflected in the weight change variable) from functional impairments arising from low WA (e.g., possible de-

[14] A parallel situation exists in studies of adult mortality, in which elevated mortality among lean subjects is due to chronic weight loss from cancer or other illnesses rather from an effect of body size or composition per se.

pressed immune function that affects the severity of disease).

In both studies the multivariate logistic regression results show that severely low weight-for-age retains a highly significant relationship with mortality even after weight change in the preceding 1–2 months is accounted for in the model. Although the effectiveness of this approach for controlling for acute weight loss is limited by the compounded measurement error in the weight change variable, the size of the weight-for-age effect [i.e., an odds ratio of 9.7 with a standard error of 2.25 in Briend and Bari (1989b)] is such that a relationship is likely to persist even if measurement error were greatly reduced (de Klerk et al. 1989).

Thus, within the limits of their respective methodologies these four studies do not support the hypothesis that the association between WA and mortality is an artefact of morbidity-induced weight loss immediately before death. Rather, the accumulated evidence lends support to the existence of a direct link between anthropometric indicators and mortality, possibly mediated through the severity and duration of illness (Martorell and Ho 1984). It is important to note, however, that the available studies did not examine whether similar results are found in mild-to-moderate, as opposed to severe, malnutrition.

Breastfeeding. Two reports in the literature, from different areas of rural Bangladesh, have documented that breastfeeding is associated with reduced risk of mortality in the month after measurement. In both cases this effect was observed only among severely malnourished children, as defined by WA < 60% (Briend and Bari 1989b) or arm circumference < 110 mm (Briend et al. 1988). In the former study this association was shown to be independent of child's age in a multivariate logistic regression. The latter study did not control for age; however, the direction of the difference in mean age between weaned (29 months) and breastfed (22 months) children suggests that the estimated effect of breastfeeding would probably be greater if age were controlled.

Although both of the above reports emphasized the positive effects of breastfeeding among severely malnourished children, they also provide evidence that breastfeeding acts as an effect modifier of the relation between anthropometric indicators and mortality. As shown in **Table 14** the mortality rate is 8–10/1,000 child-months among breastfed children in the most extreme category of malnutrition, as compared with 34–41/100 for weaned children. These differences are even greater when the mortality rate in the extreme category is examined in relation to that of the highest nutritional category (i.e., relative risks as shown in Table 14). Thus, although mortality is associated with anthropometric indicators in all cases, the effect is significantly attenuated in the presence of breastfeeding. This is reminiscent of the findings of Butz et al. (1984) that the effects of environmental factors (e.g., type of sanitation and water supply) on infant mortality are significantly affected by the presence or absence of breastfeeding.

In both of the above studies the positive effect of breastfeeding on survival, which is seen when all nutritional categories are combined, is not accounted for by better nutritional status of breastfed children. This observation, together with the evidence in one study (Briend et al. 1988) that the effect is not accounted for by cessation of breastfeeding due to intercurrent illness, is the reason for juxtaposing breastfeeding with immune status in Figure 7, rather than with nutrient intake. One interpretation is that, among these older children at least (>12 months), the primary benefit of breastfeeding may lie in its immunologic rather than nutritional properties. An alternative hypothesis is that the breastfeeding mothers in this sample also differ in their use of health services, and it is the latter which accounts for the lower mortality.

TABLE 14

Mortality in relation to anthropometric indicators and breastfeeding, Bangladesh (studies 6a and 3b)[1,2]

	Breastfed			Weaned		
Indicator level	Deaths	Child-months	Rate/1000	Deaths	Child-months	Rate/1000
Chandpur-Comilla Highway, Bangladesh						
WA < 60%	12	1,230	9.76	35	851	41.1
WA ≥ 60%	14	7,940	1.76	8	4,898	1.6
Relative risk	—	—	5.55	—	—	25.7
Matlab, Bangladesh						
AC ≤ 110 mm	8	984	8.13	20	592	33.8
AC 111–125 mm	13	6,511	2.00	1	2,098	0.4
AC > 125 mm	6	12,537	0.48	1	4,953	0.2
Relative risk	—	—	16.94	—	—	169.0

[1] Adapted from Briend and Bari (1989a) and Briend et al. (1988).

[2] WA = weight-for-age; AC = arm circumference; relative risk = rate for severe category divided by rate for normal catetory.

Seasonality. One of the most pervasive aspects of life in developing countries is the existence of seasonal variation in access to food at the household level, daily activity schedules (with implications for quality of child care), child nutritional status, morbidity and mortality. These patterns are such that the seasons with highest mortality are also those with highest morbidity, least access to health care and highest levels of malnutrition. This suggests the strong possibility that, depending upon the timing of the survey, the association between child mortality and anthropometric indicators may be at least partially confounded by season of measurement, with morbidity and child/health care acting as proximate mechanisms for the confounding (see Fig. 7).

Given the pervasiveness of this situation, it is striking that the effects of seasonality have not been systematically accounted for in the literature. Of the 28 reports reviewed here, only the one from Narangwal describes (in the text) the effect of seasonality on the relationship between anthropometry and mortality (Kielmann and McCord 1978). The study reports that "malnourished children (<70% of Harvard standard) during the first 6 months of the year (January–June) ran the highest risk of dying within 6 months. The risk of death was considerably lower if they were malnourished during the second half of the year (July–December). The risk of death within 6 months appears to be independent of the season of the survey for those at or above 80% of the Harvard weight median" (p. 1249). Thus, the verbal description clearly indicates that the effect of weight-for-age on mortality depends on the season. However, the lack of quantitative data in the report precludes drawing inferences concerning the extent to which the anthropometry-mortality relationship is itself a statistical artefact of seasonality. Thus, on the basis of one study, seasonality appears to be an effect modifier in the anthropometry-mortality relationship, but there is no direct evidence examining the possibility of seasonality as a confounder of this relationship.

Socioeconomic factors. In a manner similar to seasonality, socioeconomic status (SES) may represent a major confounding factor between child anthropometry and mortality. Referring to Figure 7, it can be seen that SES may influence mortality through some pathways that also have a strong impact on anthropometry (e.g., intake and morbidity). However, SES may also influence mortality through some pathways that save children's lives (e.g., use of health care and better quality illness management at home) but have relatively smaller impacts on anthropometry. In the latter case, confounding by SES could account for much, if not all, of the association between anthropometry and mortality.

Several studies in the literature have directly examined this possibility. The early study by Chen et al. (1980) included consideration of SES in the analysis, and two reports from the same data set have since analyzed these relationships in further detail (Chowdhury 1988, Cogill 1982). The other studies are from Iringa Region, Tanzania (Yambi 1988) and Uganda (Vella et al. 1994).

Table 15 shows that among Bangladeshi children the relationship between anthropometric deficits and mortality is remarkably stable, being found in each of the socioeconomic strata examined in two studies of this data set. The relative risk of mortality due to poor nutritional status varies between 2.16 and 4.23 across these strata. Surprisingly, both of the studies shown in this table suggest that the relative risk of mortality due to anthropometric deficits is actually greater in the *higher* economic strata (those with bigger houses and more maternal education), contrary to theoretical expectations.

The interrelationships of anthropometric indicators, mortality and socioeconomic indicators were examined in greater detail by Cogill (1982) using multivariate discriminant analysis. In a model which potentially includes age of the mother and child, parity, religion, education of mother and father, number of cows, floor area, mother's height and weight and all of the anthropometric indicators, the results show that each of the child anthropometric indicators is statis-

TABLE 15

Relationship between child anthropometry and mortality in Bangladesh, stratified by socioeconomic indicators, Bangladesh (studies 1a and 1c)[1]

SES group	Mortality rates (per 1000/year): Poor nutritional status	Mortality rates (per 1000/year): Better nutritional status	Relative risk
Matlab, Bangladesh[2] (Study 1a)			
Floor space in living quarters			
<242 sq. ft.	123.6	53.9	2.29
≥242 sq. ft.	99.5	23.5	4.23
Maternal height			
<147.5 cms.	130.9	37.9	3.45
≥147.5 cms.	82.4	38.2	2.16
Matlab, Bangladesh[3] (Study 1c)			
Maternal age and education			
<25 and no education	114.0	43.0	2.65
<25 and some education	125.0	30.0	4.17
≥25 and no education	119.0	48.0	2.48
≥25 and some education	94.0	23.0	4.09

[1] Adapted from Chen et al. (1980) and Chowdhury (1988).

[2] Nutritional status defined as above or below 85% of median height-for-age. The text of the report states that the same relationships were found with the other anthropometric indicators; however, results were not presented.

[3] Nutritional status defined as above or below 60% of median weight-for-age.

TABLE 16

Mortality rate (per 1000 per year) and relative risks by anthropometric deficits and socioeconomic status, SW Uganda (study 17)[1,2]

		Anthropometric deficit					
		Severe		Moderate		Normal	
Indicators	SES group	Mortality	(RR)	Mortality	(RR)	Mortality	(RR)
WA	High	105	(6.18)	45	(2.65)	17	(1.00)
	Medium	85	(4.47)	48	(2.53)	19	(1.00)
	Low	83	(2.59)	54	(1.69)	32	(1.00)
	All groups	91	(4.42)	48	(2.36)	20	(1.00)
HA	High	46	(2.42)	26	(1.37)	19	(1.00)
	Medium	30	(1.20)	25	(1.00)	25	(1.00)
	Low	80	(2.90)	16	(.52)	31	(1.00)
	All groups	49	(2.05)	23	(.98)	23	(1.00)
WH	High	65	(3.09)			21	(1.00)
	Medium	140	(6.36)			22	(1.00)
	Low	42	(1.08)			39	(1.00)
	All groups	94	(2.72)			25	(1.00)
AC	High	107	(7.13)	56	(3.73)	15	(1.00)
	Medium	95	(5.28)	49	(2.72)	18	(1.00)
	Low	164	(6.07)	25	(.93)	27	(1.00)
	All groups	117	(6.44)	46	(2.54)	18	(1.00)

	Definitions		
	Severe	Moderate	Normal
WA (Z)	<−2.5	−2.5 to −1.51	>1.5
HA (Z)	<−3.0	−3.0 to −2.01	>2.0
WH (Z)	<−1.50	−1.5 to −1.01	>−1.0
AC (cm)	<12.5	12.5 to 13.4	>13.5

[1] Calculated from Vella et al. (1994).
[2] WA = weight-for-age; HA = height-for-age; WH = weight-for-height; AC = arm circumference.

tically significant except for weight-for-age.[15] The magnitude of the standardized coefficients suggest that the discriminatory power of the anthropometric indicators is 2.3 times (in the case of HA) to 23 times (in the case of AC) greater than any of the SES indicators.

In the Tanzanian study (Yambi 1988), SES variables were controlled in multivariate logistic regression models that included weight-for-age and child's age. The results show that WA retains its statistical significance in relation to mortality even after controlling for maternal age (model 1), maternal education (model 2), household size and number of rooms (model 3) and household agricultural variables (model 4).

Table 16, from Uganda (Vella et al. 1994), shows the mortality rates and relative risks for four anthropometric indicators stratified by a combined index of socioeconomic status formed from 19 individual variables. As in the other studies, the association between severe deficits and mortality is apparent even within SES groups and is not significantly diminished in magnitude. The significance of this study is the opportunity it affords for examining whether a relationship persists between *moderate* deficits and mortality, after stratifying by SES, in contrast to the other studies that restricted their attention to the case of severe deficits. The results show, in general, that the relative risk for individual SES groups varies fairly widely compared with that observed for all SES groups combined. In the case of HA, WH and (especially) AC, the relative risks are higher in the high or medium SES groups than in the lowest SES group, reminiscent of the findings from Bangladesh in Table 15. The statistical significance of this variation in relative risks is uncertain, although the original paper (Vella et al. 1994) reports that there are no significant interactions between SES and anthropometric variables when tested by logistic regres-

[15] The indicators tested include WA, HA weight/height (W/H), weight/height^2, AC, arm circumference/height (AC/HT) and arm circumference/age (AC/A). The lack of significance for WA is probably due to multicollinearity with the other anthropometric indicators.

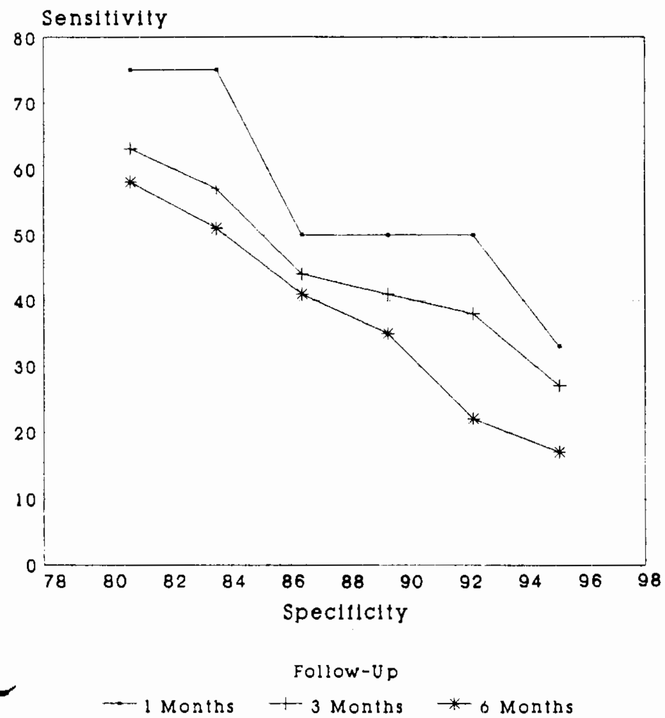

FIGURE 12 Matlab, Bangladesh (study 2c): sensitivity-specificity curves predicting mortality from arm circumference. Adapted with permission from Briend and Zimicki (1986).

sion and when considering the entire distribution of anthropometric deficits.

Thus, it appears that SES may not be a confounder of the anthropometry-mortality relationships as much as it is an effect modifier. Moreover, the accumulated evidence suggests that malnutrition, as reflected in anthropometry, may be more strongly related to mortality among the higher SES groups than among the lower SES groups. This result is contrary to theoretical expectations and requires further investigation. Additional analysis of these relationships is provided in Pelletier et al. (1994a) in this supplement.

Length of follow-up

A question with important programmatic implications is the extent to which the predictive ability of anthropometric indicators is attenuated as the length of follow-up is extended or, put another way, the extent to which nutrition-related deaths are concentrated in the period immediately after measurement. Although most growth monitoring programs strive for monthly measurements, usually this can only be attained in the face of, or at the expense of, constraints on mothers' time and travel costs, staff time in health facilities, and perhaps sustained motivation levels in community-based programs. Depending on the strength of the length of follow-up effect and a variety of local considerations, it may therefore be appropriate to consider trade-offs between screening efficiency, frequency of measurement and choice of indicators.

In order to examine this question systematically it would be necessary to compare the sensitivity-specificity distributions of various indicators, across many cutoff points and over varying follow-up periods unconfounded by maturation and seasonal effects. Although several studies have provided data related to length of follow-up in general (Table 1, studies 1a, 2a, 2c, 5, 6b, 7 and 12), none of them provides the type of systematic analysis described above. Nonetheless, most of these studies agree in showing that mortality prediction is inversely related to length of follow-up. The notable exception is the study by Chen et al. (1980), which found that the relative risk of mortality for severely malnourished children was greater during the second year of follow-up than in the year immediately after measurement. This enigma is even more striking in that it was true for indicators of acute malnutrition (WA and WH) but not for chronic malnutrition (HA). Similar findings are evident in a study from Northern Malawi (Pelletier et al. 1994a).

Figure 12 (taken from Briend and Zimicki 1986) illustrates the effect of follow-up length on the sensitivity and specificity of simple arm circumference over a range of cutoff points. Prediction is clearly greatest in the mo immediately after measurement and continues to decline beyond 3 months of follow-up. In the original report of this study (study 2a, which used AC/HT as the indicator) it was observed that the relative risk declines rapidly from 19.8 in the first month to 12.2 in months 1–3 and 4.5 by months 4–6, leveling off at about 3.0 from that point through 18 months follow-up. The interpretation of both reports is seriously hampered, however, by the fact that all children in this study were measured in 1 month (De-

TABLE 17

Mortality and relative risks of mortality for severely malnourished children as defined by anthropometric indicators over two follow-up periods, Bangladesh (study 5)[1,2]

Indicator/ cutoff point	Follow-up months 1–3: Mortality rate	Follow-up months 1–3: Relative risk	Follow-up months 4–6: Mortality rate	Follow-up months 4–6: Relative risk
WA < 60%	19.7	24.6	11.8	14.8
HA < 85%	9.4	7.8	6.0	2.5
WH < 80%	13.6	5.4	1.4	0.5
AC < 121	23.4	16.7	13.4	7.9
ACA < 75%	17.9	10.5	11.0	6.5
ACHT < 80%	15.2	10.1	8.4	5.6

[1] Data from Alam et al. (1989).

[2] Mortality rate = deaths per 1000 children per 3-mo period; Relative risk = defined in relation to the group above the cutoff point specified for each indicator.