Estimating the burden of disease attributable to childhood and maternal undernutrition in South Africa in 2000

Nadine Nannan, Rosana Norman, Michael Hendricks, Muhammad A Dhansay, Debbie Bradshaw and the South African Comparative Risk Assessment Collaborating Group

Objectives. To estimate the disease burden attributable to being underweight as an indicator of undernutrition in children under 5 years of age and in pregnant women for the year 2000.

Design. World Health Organization comparative risk assessment (CRA) methodology was followed. The 1999 National Food Consumption Survey prevalence of underweight classified in three low weight-for-age categories was compared with standard growth charts to estimate population-attributable fractions for mortality and morbidity outcomes, based on increased risk for each category and applied to revised burden of disease estimates for South Africa in 2000. Maternal underweight, leading to an increased risk of intra-uterine growth retardation and further risk of low birth weight (LBW), was also assessed using the approach adopted by the global assessment. Monte Carlo simulation-modelling techniques were used for the uncertainty analysis.

Setting. South Africa.

Subjects. Children under 5 years of age and pregnant women.

Outcome measures. Mortality and disability-adjusted life years (DALYs) from protein- energy malnutrition and a fraction of those from diarrhoeal disease, pneumonia, malaria, other non-HIV/AIDS infectious and parasitic conditions in children aged 0 - 4 years, and LBW.

Results. Among children under 5 years, 11.8% were underweight. In the same age group, 11 808 deaths (95% uncertainty interval 11 100 - 12 642) or 12.3% (95% uncertainty interval 11.5 - 13.1%) were attributable to being underweight. Protein-energy malnutrition contributed 44.7% and diarrhoeal disease 29.6% of the total attributable burden. Childhood and maternal underweight accounted for 2.7% (95% uncertainty interval 2.6 - 2.9%) of all DALYs in South Africa in 2000 and 10.8% (95% uncertainty interval 10.2 - 11.5%) of DALYs in children under 5.

Conclusions. The study shows that reduction of the occurrence of underweight would have a substantial impact on child mortality, and also highlights the need to monitor this important indicator of child health.

S Afr Med J 2007; 97: 733-739.

Undernutrition, as manifested by underweight, wasting and stunting, has been identified as a major problem affecting about 200 million children under the age of 5 years in developing countries.[1] Undernutrition in mild, moderate and severe forms can have significant and long-lasting consequences on the health of children. The reduction of underweight children is a key indicator of the first Millennium Development Goal (MDG),[2] which aims to reduce poverty and hunger between 1990 and 2015.

Changes in weight-for-age are significantly associated with changes in child mortality, independent of socio-economic and other health-related changes. It is estimated that a 5% improvement in weight-for-age could reduce child and under-5 mortality by 30% and 13% respectively.[3] Aside from increased risk of mortality, undernutrition also has long-term effects such as delayed motor development, impaired cognitive function and school performance,[4] and reduced work capacity and reproductive health in adulthood.[5]

The determinants of undernutrition are interrelated and include immediate (inadequate dietary intake and infections), underlying (household food insecurity, inadequate caring practices and poor environments), and basic or structural (socio-economic and political) factors. With regard to the immediate causes, the diet of the undernourished child is lacking in energy, protein and vital micronutrients such as vitamin A, iron, zinc and calcium.[6] Important in the causal pathway leading to underweight is the malnutrition-infection cycle, whereby children who are underweight are at increased risk of infectious diseases such as diarrhoea and pneumonia, and at substantially increased risk of mortality.[7] In 10 cohort studies undernutrition was found to contribute to 50% of childhood deaths, with a direct relationship between risk of mortality and degree of underweight.[1] The simultaneous presence of undernutrition and infection greatly increases the risk of child mortality,[8] with extended duration of infections among malnourished children playing an important role.[9,10]

Burden of Disease Research Unit, South African Medical Research Council, Cape Town

Nadine Nannan, MSc
Rosana Norman, PhD
Debbie Bradshaw, DPhil (Oxon)

School of Child and Adolescent Health, University of Cape Town
Michael Hendricks, MB ChB, MMed (Paed), MTropPaed (Liverpool), DCH

Nutritional Intervention Research Unit, South African Medical Research Council, Tygerberg, Cape Town
Muhammad A Dhansay, MB ChB, FCPaed

Corresponding author: *N Nannan (nadine.nannan@mrc.ac.za)*

Maternal underweight, leading to increased risk of intra-uterine growth retardation (IUGR) and further risk of low birth weight (LBW), is also associated with increased mortality risk in early childhood.

As yet there is no regular series of anthropometric data for children in South Africa. The 1999 National Food Consumption Survey[11] among children aged 1 - 9 years showed that 10.3% were underweight, 21.6% were stunted and 3.7% were wasted. The survey found that children living on commercial farms, in tribal and rural areas and informal urban areas were more severely affected than children living in formal urban areas. Compared with another population-based survey conducted by the South African Vitamin A Consultative Group conducted in 1994,[12] there has been little change in anthropometrical status in the 5-year period, with underweight being 9.3%, stunting 23% and wasting 2.6% among children aged 6 - 71 months. This earlier survey also found a higher prevalence of underweight in rural children and those whose mothers' educational status was poor.

In the South African comparative risk assessment study, as in the global assessment,[13] undernutrition has been disaggregated into underweight and micronutrient deficiency (which are not additive). The aim of this study was to estimate the burden of disease attributed to underweight as an indicator for undernutrition in children under the age of 5 years and in pregnant women between the ages of 15 and 49 years in South Africa for the year 2000. Burden attributable to iron-deficiency anaemia and vitamin A deficiency have been estimated separately in other articles in this supplement.[14,15]

Methods

Comparative risk assessment (CRA) methodology was used, as developed by the World Health Organization (WHO).[6,13,16] The amount of disease burden attributable to childhood and maternal underweight was estimated by comparing the current observed prevalence of exposure with a counterfactual risk factor distribution conferring the lowest possible population risk (the theoretical minimum distribution). This assessment of the risk factor underweight is modelled on the approach used in the WHO global CRA project,[6] which utilises the National Center for Health Statistics (NCHS)/WHO[17] reference median underweight for children defined in three low weight-for-age categories: < –3 standard deviations (SDs); between –3 and –2 SDs; and between –2 and –1 SDs. Weight-for-age is used because it is thought to be a better index of overall child nutritional status and is commonly available in less-developed countries. A limitation of this measure is that it does not distinguish between wasting and stunting. However, the WHO states that it has a high predictive value of child undernutrition, because underweight or low weight-for-age incorporates aspects of both wasting and stunting.[18]

The data source for prevalence and population distribution of exposure in children under 5 was the National Food Consumption Survey of 1999.[11] The NCHS/WHO[17] reference table was used as the theoretical minimum risk distribution of underweight (Table I). The prevalence of underweight in children under 5 years of age according to the weight-for-age categories is shown in Table I alongside the proportions that are expected in the categories based on the NCHS tables.

Following the framework developed by Fishman *et al.*,[6] the contribution of underweight to child mortality and morbidity was measured indirectly through its contribution as a risk factor for several diseases, and added to the direct effects of malnutrition. The outcomes chosen for review were globally significant diseases commonly associated with undernutrition, and included child mortality from diarrhoeal disease, pneumonia (lower respiratory infections), malaria and measles. The morbidity outcomes were selected on the basis of availability of good-quality data.[6]

The relationship between low weight-for-age among children and mortality was analysed as a multiple categorical variable having four levels of exposure: the three weight-for-age categories, and a reference category > –1 SD, while morbidity was analysed as a dichotomous variable comparing weight-for-age category < –2 SDs with the reference category > –2 SDs.[6] The relative risks (RRs) for cause-specific mortality based on low weight-for-age categories identified by the WHO Expert Working Group on underweight were used (Table II). Information on diarrhoeal disease and pneumonia deaths from 10 prospective studies from sub-Saharan Africa and Asia[6] were included in the regression models that determined these RRs.

The global assessment estimated the increased incidence of infection and risk of other morbidities associated with underweight status through a systematic literature review and

Table I. Distribution of underweight categories in children under 5 in South Africa and the standard population

Underweight category		South Africa* (%)	NCHS/WHO reference[17] theoretical minimum (%)
No risk	> –1 SD	58.4	84.1
	–2 SD to –1 SD	30.0	13.6
At risk	–3 SD to –2 SD	9.7	2.1
	< –3 SD	1.9	0.1

*South African data source: 1999 National Food Consumption Survey[11] (children under 1 year of age not included).

meta-analysis of published data.[6] Owing to a paucity of local data, this analysis used the same RRs, which are shown in Table III.

Population-attributable fractions (PAFs) by cause were calculated in customised Excel spreadsheets using the formula:

$$PAF = \frac{\sum_{i=1}^{k} p_i (RR_i - 1)}{\sum_{i=0}^{k} p_i (RR_i - 1) + 1}$$

where p_i is the prevalence of exposure level i, RR_i is the relative risk of disease in exposure level i, and k is the total number of exposure levels. The PAFs were then applied to the revised 2000 burden of disease estimates of deaths and DALYs for the relevant disease and injury categories.[19] A model-based approach was used to adjust for under-reporting of deaths in the vital registration and the ill-defined causes were redistributed proportionately across defined causes by age and sex. The total estimated burden from protein-energy malnutrition was directly attributed to this risk factor.

The relationship between maternal underweight status and the risk of neonatal mortality was estimated in two stages, assuming that the pathway is mediated through IUGR resulting in LBW and an increased risk of mortality during the neonatal period. The overall PAF of neonatal mortality due to maternal underweight was calculated as the product of the PAF for IUGR due to low maternal body mass index (BMI) and the PAF for neonatal mortality due to IUGR weighted by the proportions of births in the population in the age categories 15 - 29 and 30 - 49 years, based on the estimated number of births in South Africa 2000 from the ASSA2002 model.[20]

BMI, the index of adult nutritional status, was selected as the indicator of maternal underweight. The cut-off for underweight was taken as a BMI < 20 kg/m^2. Due to a lack of nationally representative data on the prevalence of low BMI in pregnant women, we estimated the prevalence of BMI < 20 kg/m^2 in women of reproductive age in the 15 - 29 and 30 - 49-year age groups using the 1998 South African Demographic and Health Survey,[21] with observed proportions of 18.7% and 6.6% in the respective age groups. The attributable fraction of IUGR associated with pre-pregnancy underweight was calculated using a RR of IUGR due to BMI < 20 kg/m^2 of 1.8, as determined by the global CRA project[6] and applied to the prevalence of underweight in women of child-bearing age.

The second step was to calculate the PAF for neonatal mortality associated with IUGR. Due to lack of local data we used the WHO African Region (AFR-E which includes South Africa) AFR-E estimate of 9.3% for IUGR-LBW births as a percentage of total live births for this region.[6] We used a risk ratio of 6 for neonatal death due to IUGR as selected by Fishman *et al.*[6]

Monte Carlo simulation-modelling techniques were used to present uncertainty ranges around point estimates that reflect all the main sources of uncertainty in the calculations. The @ RISK software version 4.5 for Excel[22] was used, which allows multiple recalculations of a spreadsheet each time choosing a value from distributions defined for input variables. For the input variables related to the prevalence of BMI < 20 kg/m^2 in women of reproductive age we used the standard errors for the observed proportions in the 15 - 29 and 30 - 49-year age groups from the 1998 South African Demographic and Health Survey data specifying a normal distribution. For the prevalence in children under 5, we assumed that the observed proportions in each category could vary by 5%, and specified a triangular distribution with 3 points (minimum, most likely

Table II. Relative risk (95% CI) of mortality associated with low weight-for-age categories estimated from regression analysis,* by cause of death

Cause of death	> –1 SD	–1 to –2 SDs	–2 to –3 SDs	< –3 SDs
Diarrhoeal disease	1	2.32 (1.93 - 2.79)	5.39 (3.73 - 7.79)	12.5 (7.19 - 21.73)
Pneumonia	1	2.01 (1.63 - 2.47)	4.03 (2.67 - 6.08)	8.09 (4.36 - 15.01)
Malaria	1	2.12 (1.48 - 3.02)	4.48 (2.20 - 9.15)	9.49 (3.25 - 27.66)
Measles	1	1.73 (1.32 - 2.28)	3.01 (1.74 - 5.21)	5.22 (2.29 - 11.88)
All-cause	1	2.06 (1.77 - 2.39)	4.24 (3.13 - 5.73)	8.72 (5.55 - 13.72)

Source: Fishman *et al.*, 2004.[6]
*Calculated at –3.5, –2.5 and –1.5 versus 0.5 SD weight-for-age.
SD = standard deviation.

Table III. Relative risk of morbidity associated with weight-for-age < –2 SD

Morbidity outcome	> –2 SD	Relative risks (95% CI)
Diarrhoea incidence	1	1.23 (1.12 - 1.35)
Pneumonia incidence	1	1.86 (1.06 - 3.28)
Clinical malaria incidence	1	1.31 (0.92 - 1.88)

Source: Fishman *et al.*, 2004.[6]

and maximum). For the RR estimates we specified a normal distribution with the natural logarithm of the published RR estimates as the entered means of the distribution, and the standard errors of these RR estimates calculated from the natural logarithms of the published 95% confidence intervals (CIs). For each of the output variables (namely attributable burden as a percentage of total burden in South Africa 2000), 95% uncertainty intervals were calculated bounded by the 2.5th and 97.5th percentiles of the 2000 iteration values generated.

Results

The distribution of underweight in children under 5 showed that 11.6% of children had weights that were < 2 SD from the NCHS median weight for age (Table I), and more than 40% of children were at risk of adverse health outcomes related to underweight.

The attributable fractions of mortality and morbidity and the attributable burdens for the selected conditions are shown in Table IV. There were 11 808 deaths attributed to underweight status, and protein-energy malnutrition, diarrhoeal disease and pneumonia accounted for 38.3%, 33.1% and 15.3% of these respectively. Other infectious causes (excluding HIV/AIDS, maternal conditions, and perinatal conditions) accounted for 9.3% of all attributable deaths. The overall attributable DALYs by cause are shown in Fig. 1. It can be seen that protein-energy malnutrition contributes almost half (44.7%) of the total attributable burden, followed by diarrhoeal disease (29.6%) and pneumonia (13.7%). The attributable years of life lost (YLLs) account for most of the burden (YLLs = 399 299).

This analysis found that 3.5% of the burden from LBW was attributable to maternal underweight status. Table IV shows the burden attributable to underweight out of the total burden in all persons and children under 5 in South Africa, 2000, as well as the 95% uncertainty intervals around these estimates. The burden attributable to childhood and maternal underweight in 2000 accounted for 12.3% of the deaths (95% uncertainty interval 11.5 - 13.1%) and 10.8% of the total DALYs (95% uncertainty interval 10.2 - 11.5%) in children under 5 years old.

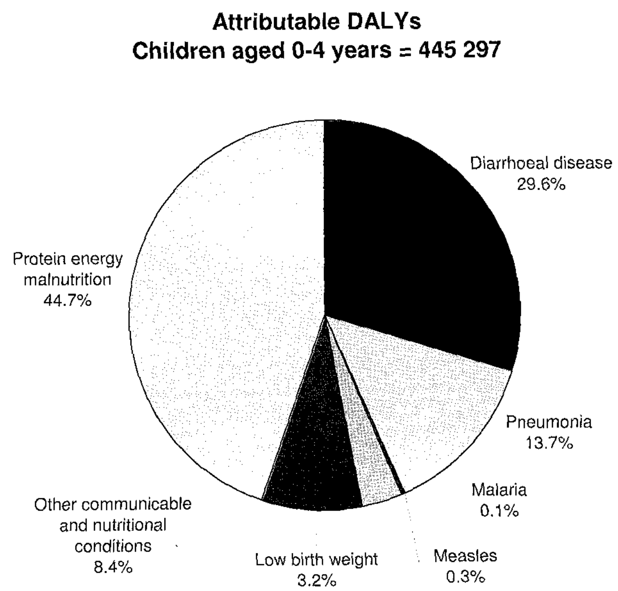

Fig. 1. Burden attributable to childhood and maternal underweight, South Africa, 2000.

Discussion

The findings of this study highlight the substantial burden due to underweight status in children younger than 5 years in South Africa. Nearly 12 000 deaths among children under

Table IV. Burden attributable to childhood and maternal underweight in South Africa, 2000

Related outcomes	PAF (%) Mortality	PAF (%) Morbidity	Attributable deaths	Attributable DALYs
Diarrhoeal disease	36.8	2.8	3 912	131 734
Pneumonia	30.0	7.3	1 807	60 993
Malaria	32.5	2.1	12	408
Measles	23.2	-	45	1 532
Other communicable and nutritional conditions*	31.2	-	1 100	37 191
PEM	100.0	-	4 528	199 020
LBW	3.5	-	405	14 419
Total burden			**11 808**	**445 297**
95% uncertainty interval			11 100 - 12 642	421 362 - 473 504
% of total child burden			**12.3%**	**10.8%**
95% uncertainty interval			11.5% - 13.1%	10.2% - 11.5%
% of total all age burden			**2.3%**	**2.7%**
95% uncertainty interval			2.1% - 2.4%	2.6% - 2.9%

*Other communicable and nutritional conditions in children 0 - 4 years (applied only to group I causes excluding HIV/AIDS, maternal conditions, perinatal conditions, and PEM).
PAF = population-attributable fractions; DALYs = disability-adjusted life years; PEM = protein-energy malnutrition; LBW = low birth weight.

5 years of age in 2000 were attributable to underweight, accounting for 12.3% (95% uncertainty interval 11.5 - 13.1%) of all deaths in this age group. However, this underestimates the true burden attributable to underweight, since this analysis did not quantify the impact that underweight has on childhood development. An estimate of the true burden would include the adverse effects on the intellectual and emotional development of children and the role that maternal undernutrition plays as a risk factor for maternal mortality. The analysis also did not consider the effects of underweight status on work capacity or the effect of IUGR on childhood development. Much of the impact of undernutrition is still unknown, including the role of undernutrition on the progression of HIV and AIDS, early undernutrition in potentiating chronic disease,[23] or the effect of adult undernutrition on susceptibility to infection, especially among the elderly. The mediating effects of underweight leading to an increased risk of infectious diseases and growth faltering with increased risk of mortality that have been described in the malnutrition infectious disease cycle framework[24] are likely to occur in the case of HIV-infected children and their progression to AIDS. However, there are insufficient data to be able to quantify the burden of HIV/AIDS related to underweight and hence this burden was not included in this analysis.

In many respects the findings of this study are different from what might have been expected. In the global assessment[6] the attributable fractions of mortality associated with weight-for-age below –1 SD were greater than in the local assessment: 60.7% for diarrhoeal disease, 52.3% for pneumonia, 44.8% for measles, and 57.3% for malaria. Worldwide, about 10.5% of deaths due to LBW could be attributed to maternal underweight, about 3 times higher than local estimates. This is attributed to the lower prevalence of underweight among South African women. The estimated 12.3% of child deaths for South Africa is smaller than the global maternal and child underweight risk factor assessment finding of 34.7%. There are 2 main reasons for this difference. Firstly, the prevalence of underweight in South Africa is lower than in many other developing countries. Secondly, a high proportion of child deaths in South Africa was due to HIV/AIDS (35.1%), reducing the relative proportion of other causes.[25]

The findings of this study also differ from the global study[6] in the relative composition of the attributable burden. In the global study 4.1% of the attributable deaths are a direct consequence of malnutrition, while in the South African study this accounts for 38.3% of the attributable deaths. This raises the question of whether the malnutrition-related mortality estimate is perhaps too high, given the observed prevalence of malnutrition measured according to weight-for-age. However, this is not considered likely. Groenewald *et al.*[26] identified extensive misclassification of AIDS deaths to indicator conditions including protein-energy malnutrition in the year 2000. While efforts were made to adjust for this misclassification by making use of the cause-of-death profile from an earlier period (1996) when the impact of AIDS was lower, it is possible that there is still some misclassification. However, there would also be misclassification to lower respiratory and diarrhoeal disease making it unlikely that the South African profile would differ substantially.

Another possible explanation is that kwashiorkor is the major cause of the malnutrition mortality in South Africa. Weight-for-age may not be a good indicator of this form of malnutrition as a result of the oedema that accompanies it. In a rural demographic surveillance area, kwashiorkor unrelated to HIV was common at the beginning of 1990s and remained a persistent cause of death over a 10-year period.[27]

The issue of the most appropriate measure to indicate undernutrition status has recently been quantitatively explored in Senegal.[28] The findings show that greater accuracy in assessing the 'whole nutritional status' is achieved by using a composite measure constructed from weight-for-age (capturing underweight) and height-for-age (capturing stunting), particularly in the calculation of population-attributable risk. Furthermore, the composition of the attributable burden may be the result of the relatively good access to curative health services in South Africa, reducing the risk of dying from infections – even in the context of poverty and undernutrition – and highlighting the failure to prevent the underlying problem.

It is important to consider that undernutrition as assessed by the underweight indicator may be associated with certain micronutrient deficiencies.[29] A review of the literature to determine which micronutrients are causal to growth faltering in children[30] concludes that there is strong evidence to support mild and moderate zinc deficiency in growth faltering, while iron and vitamin A tend to be growth limiting only when there are severe deficiencies of these micronutrients. The association of underweight with these deficiencies means that some of the risk attributed to underweight may be due to these micronutrient deficiencies. Iron-deficiency anaemia and vitamin A deficiency have been estimated separately[14,15] but it would be important to estimate the joint effect of all these aspects of undernutrition, and to take into account the mediating effects of zinc deficiency in retarding growth.

Breastmilk is an important source of micronutrients for babies. However in an era of HIV/AIDS previous guidelines promoting exclusive breastfeeding for 6 months have been modified. The WHO/UNICEF guidelines,[31] adopted by South Africa, recommend that HIV-positive women should avoid breastfeeding if the conditions for replacement feeding (acceptable, affordable, sustainable and safe) are in place. In situations where replacement feeding is not viable, exclusive breastfeeding for 3 months has been demonstrated to pose less risk than mixed feeding.[32] On the other hand for babies whose mothers are HIV-negative, the contribution of 6 months' exclusive breastfeeding on health is substantial.

For example, the risks of diarrhoea- and pneumonia-related mortality for children 0 - 5 months who are exclusively breastfed are respectively 6 and 2.5-fold less than for those who are not exclusively breastfed. Despite the known benefits, the prevalence of exclusive breastfeeding, particularly for durations longer than 2 months, remains dismal in South Africa.[21]

The first MDG to halve the proportion of people suffering from hunger between 1990 and 2015 has been set, with an annual reduction rate of 2.7%. Sadly, only 17% of countries in sub-Saharan Africa saw any change in child undernutrition in the 1990s. South African data also show no change in the percentage of underweight children during this period. Poverty, hunger and poor household food security are among the main factors contributing to high rates of childhood underweight, especially in rural areas. The Income and Expenditure Survey of 2000, using a poverty line of R430 per month per capita, found that about 75% of children lived in poor households.[33] The National Food Consumption Survey found that 52% of children aged 1 - 9 years experienced hunger, and a further 23% were at risk of hunger.[11] Furthermore, there are indications that unsafe water, sanitation and hygiene play an important role in undernutrition.[34] Hence, a substantial proportion of the burden could be prevented if interventions were implemented that would substantially reduce poverty and ensure access to basic services.

Improvements in social security (i.e. social grants) can lead to increased spending on basic foodstuffs and education in poor households, thereby contributing to reducing the problems of poor household food security and underweight in children. A recent study by the Economic Policy Research Institute[35] examined the impact of receiving social grants on household access to food, basic services, health and education. They showed that in households in the lowest income brackets, which were most likely to be eligible for social grants, school attendance rates were higher, hunger was less prevalent, spending on food and basic household services increased, and spending on alcohol, tobacco and gambling was less than in households with comparable income from other sources. The main reason postulated for this was that income that went to female heads of households and female pensioners was more likely to be used for positive social and human capital outcomes.

Similarly, evidence from KwaZulu-Natal highlights two important findings with regard to the Child Support Grant. Firstly, the grant significantly improved nutritional status as measured by height-for-age, when received for a sufficient length of time in children under 3 years.[36] Secondly, this finding supports the recommendation from de Klerk *et al.*,[37] since the analysis shows that this grant is reaching the children it is intended for, despite the fact that the grant is an unconditional one. In March 2006 an estimated 7.1 million children (i.e. 80%) eligible for the Child Support Grant had access to it. There was also an increase in the take-up of the Foster Child Grant and the Care Dependency Grant between April 2004 and March 2006 of 57% and 15%, respectively.[38]

Recommendations

In order to reduce the prevalence of underweight, a multisectoral approach is needed. Addressing underweight requires input not solely from the health sector; it must include measures that address household poverty and food security, fixing prices of basic foodstuffs and ensuring basic nutrition as a basic human right as enshrined in the Constitution. Policies aimed at alleviating poverty must give attention to the provision of social assistance grants to poor households, rather than just to special groups. In the case of the Child Support Grant, urgent revision of household income cut-offs is required so that they incorporate inflation increases since 1998 when it was last set. Also, consideration should be given to widening access to the Child Support Grant by extending it to the age of 18 years and ensuring full coverage of eligible children.[39] Attention must also be given to ensuring basic services, e.g. clean water and adequate sanitation,[40] and improvements in basic infrastructure, e.g. roads and transport, especially in resource-poor settings.

A second important component to improving the nutritional status of children and reducing mortality among under-5s is strengthening of the health sector response, particularly at primary care level. This includes the following.

1. Effective implementation of existing health and nutrition interventions such as the promotion, protection and support of breastfeeding, safe and effective complementary feeding, growth monitoring and promotion, and micronutrient supplementation.[14,15] The school feeding programme is well placed to detect potential undernutrition among children attending schools, but a similar programme is needed to ensure that children under 5 do not become vulnerable to underweight at older ages, which must be targeted during pregnancy and between birth and around 2 years of age.

2. Strengthening of strategies such as the Integrated Management of Childhood Illness, which would link the nutrition interventions to those aimed at preventing and treating childhood illnesses.

3. Provision of sufficient skilled health care workers to implement health and nutrition interventions for children at the primary level of care.

4. Urgent development of community-based approaches to address undernutrition of children and ensure household food security.

This study has highlighted the need to monitor the nutritional status of children routinely, as well as to evaluate the programmes currently in place. Finally, more research is required to understand the synergistic effects that HIV may be having on other infections and underweight, leading to increased mortality in young children.

The other members of the Burden of Disease Research Unit of the South African Medical Research Council: Pam Groenewald, Michelle Schneider, Jané Joubert, Desireé Pieterse, Beatrice Nojilana, Jovial Wessie, Elize de Kock and Karin Barnard are thanked for their valuable contribution to the South African Comparative Risk Assessment Project. We are extremely grateful to Professor Robert Black, Johns Hopkins School of Public Health, for sending early drafts of the global review chapters, for his advice and guidance, and for critically reviewing the manuscript. We also thank: Associate Professor Theo Vos of Queensland University for giving expert advice during the process of developing spreadsheets; Professor Demetre Labadarios and Dr Hannelie Nel for providing access to the National Food Consumption Survey data; Ms Ria Laubscher of the MRC for statistical assistance; and Dr Lesley Bourne for input from the inception of the project. Ms Leverne Gething is gratefully acknowledged for editing the manuscript. Our sincere gratitude is expressed for all these valuable contributions.

References

1. Black RE, Morris SS, Bryce J. Where and why are 10 million children dying every year? *Lancet* 2003; 361: 2226-2234.
2. United Nations. *United Nations Millennium Declaration. Resolution Adopted by the General Assembly Fifty-fifth Session Agenda Item 60 (b). 2000.* http://www.un.org/millennium/ (last accessed 22 June 2006).
3. Pelletier DL, Frongillo EA. Changes in child survival are strongly associated with changes in malnutrition in developing countries. *J Nutr* 2003; 133: 107-109.
4. Pollitt E. *Malnutrition and Infection in the Classroom.* Paris: UNESCO, United Nations Press, 1990.
5. Haas JD, Martinez, EJ, Murdoch E, Conlisk E, Rivera JA, Martorell R. Nutritional supplementation during the preschool years influences body size and composition of Guatemalan adolescents. *J Nutr* 1995; 125: 1078S-1089S.
6. Fishman S, Caulfield LE, de Onis M, *et al.* Childhood and maternal undernutrition. In: Ezzati M, Lopez AD, Rogers A, Murray CJL, eds. *Comparative Health Quantification of Health Risks.* Vol. 1. Geneva: World Health Organization, 2004.
7. Mosley HW, Chen LC. An analytical framework for the study of child survival in developing countries. *Population and Development Review* 1984; 10: 25-45.
8. Schroeder DG. Malnutrition. In: Semba RD, Bloem MW, eds. *Nutrition and Health in Developing Countries.* Totowa, New Jersey: Humana Press, 2001: 393-426.
9. Black RE, Brown KH, Becker S. Malnutrition is a determining factor in diarrhoeal duration, but not incidence, among young children in a longitudinal study in rural Bangladesh. *Am J Clin Nutr* 1984; 39: 87-94.
10. Guerrant RL, Schorling JB, McAuliffe JF, Auxiliadora de Souza M. Diarrhoea as a cause and an effect of malnutrition: diarrhoea prevents catch-up growth and malnutrition increases diarrhoea frequency and duration. *Am J Trop Med Hyg* 1992; 47: 28-35.
11. Labadarios D, Steyn NP, Maunder E, *et al.* The National Food Consumption Survey (NFCS): South Africa, 1999. *Public Health Nutr* 2005; 8: 533-543.
12. Labadarios D, Middelkoop A, eds. *Children Aged 6 - 71 Months in South Africa, 1994: Anthropometric, Vitamin A and Iron Status. Report of the South African Vitamin A Consultative Group (SAVACG).* Stellenbosch: Stellenbosch University, 1995.
13. Ezzati M, Lopez AD, Rodgers A, Vander Hoorn S, Murray CJL and the Comparative Risk Assessment Collaborating Group. Selected major risk factor and global and regional burden of disease. *Lancet* 2002: 360: 1347-1360.
14. Nojilana B, Norman R, Dhansay MA, Labadarios D, van Stuijvenberg ME, Bradshaw D and the South African Comparative Risk Assessment Collaborating Group. Estimating the burden of iron deficiency anaemia in South Africa in 2000. *S Afr Med J* 1997; 97: 741-746 (this issue).
15. Nojilana B, Norman R, Bradshaw D, van Stuijvenberg ME, Dhansay MA, Labadarios D and the South African Comparative Risk Assessment Collaborating Group. Estimating the burden of Vitamin A deficiency in South Africa in 2000. *S Afr Med J 1997; 97:* 748-753 (this issue).
16. World Health Organization. *The World Health Report 2002. Reducing Risks, Promoting Healthy Life.* Geneva: WHO, 2002. http://www.who.int/whr (last accessed 14 March 2007).
17. World Health Organization. *Global Database on Child Growth and Malnutrition.* Geneva: WHO, 1997.
18. World Health Organization. Physical status: The use and interpretation of anthropometry. Report of a WHO Expert Committee. *World Health Organ Tech Rep Ser* 1995; No. 854.
19. Norman R, Bradshaw D, Schneider M, Pieterse D, Groenewald P. *Revised Burden of Disease Estimates for the Comparative Risk Factor Assessment, South Africa 2000.* http://www.mrc.ac.za/bod/reports.htm (last accessed 15 July 2006).
20. Actuarial Society of South Africa. *ASSA2002 AIDS and Demographic Model, 2004.* http://www.assa.org.za/ (last accessed 22 June 2006).
21. Department of Health, Medical Research Council, Macro International. *South Africa Demographic and Health Survey 1998 Full Report.* Pretoria: DOH, 2001.
22. Palisade Corporation. @Risk Software Advance Risk Analysis for Spreadsheets. Version 4.5. New York: Palisade Corporation, 2002.
23. Barker DJ. The fetal and infant origins of disease. *Eur J Clin Invest* 1995; 25: 457-463.
24. Van Norren B, Van Vianen HAW. *The Malnutrition-Infectious Syndrome and its Demographic Outcome in Developing Countries.* The Hague: Programming Committee for Demographic Research, 1986.
25. Bradshaw D, Groenewald P, Laubscher R, *et al.* Initial burden of disease estimates for South Africa 2000. *S Afr Med J* 2003; 93: 682-688.
26. Groenewald P, Nannan N, Bourne D, Laubscher R, Bradshaw D. Identifying deaths due to AIDS in South Africa. *AIDS* 2005; 19: 193-201.
27. Khan K. *Dying to Make A Fresh Start: Mortality and Health Transition in a New South Africa. Umea University Medical Dissertations New Series No 1111056.* Umea: Umea University, 2006.
28. Garenne M, Maire B, Fontaine O, Briend A. Distributions of mortality risk attributable to low nutritional status in Niakhar, Senegal. *J Nutr* 2006; 136: 2893-2900.
29. Bhan MK, Sommerfelt H, Strand T. Micronutrient deficiency in children. *Br J Nutr* 2001; 85: S199-203.
30. Rivera JA, Hotz C, Gonzalez-Cossio T, Neufeld L, Garcia-Guerra A. Animal source foods to improve micronutrient nutrition and human function in developing countries. *J Nutr* 2003; 133:4010S-4020S.
31. WHO/UNICEF/UNFPA/UNAIDS. *HIV and Infant Feeding: A Guide for Health-Care Managers and Supervisors* (revised). Geneva: World Health Organization, 2003.
32. Coovadia HM, Rollins NC, Bland RM, *et al.* Mother to child transmission of HIV-1 infection during exclusive breastfeeding in the first 6 months of life: an intervention cohort study. *Lancet* 2007; 369: 1107-1116.
33. Coetzee E, Streak J, eds. *Monitoring Child Socio-economic Rights in South Africa: Achievements and Challenges.* Cape Town: Idasa Publishing, 2004.
34. Prüss-Üstün A, Corvalán C. *Preventing Disease Through Healthy Environments: Towards an Estimate of the Environmental Burden of Disease.* Geneva: World Health Organization, 2006. http://www.who.int/quantifying_ehimpacts/publications/preventingdisease/en/index.html (last accessed 25 August 2006).
35. Samson M, Lee U, Ndlebe A, *et al. The Social and Economic Impact of South Africa's Social Security System.* EPRI Research Paper 37. Cape Town: Economic Policy Research Institute, 2004. http://www.epri.org.za/rp37.doc (last accessed 7 May 2007).
36. Woolard I, Carter M, Aguero J. *The Impact of Unconditional Cash Transfers on Nutrition: The South African Child Support Grant.* http://www.aae.wisc.edu/carter/papers/acw.pdf (last accessed 30 May 2007).
37. De Klerk M, Drimie S, Aliber M, *et al. Food Security in South Africa: Key Policy Issues for the Medium Term.* Pretoria: Human Sciences Research Council, 2004.
38. Leatt A. *Grants for Children: A Brief Look at the Eligibility and Take-up of the Child Support and Other Cash Grants.* Working Paper No. 5. Cape Town: Children's Institute, University of Cape Town, 2006.
39. Monson J, Hall K, Smith C, Shung-King M, eds. *South African Child Gauge 2006.* Cape Town: Children's Institute, University of Cape Town, 2006.
40. Lewin S, Norman R, Nannan N, Thomas E, Bradshaw D and the South African Comparative Risk Assessment Collaborating Group. Estimating the burden from unsafe water and lack of sanitation and hygiene in South Africa, 2000. *S Afr Med J* 1997; 97: 755-762 (this issue).