



KENNETH MALETA

Growth and Undernutrition
in
Rural Malawian Children



ACADEMIC DISSERTATION

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ACADEMIC DISSERTATION

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SUMMARY

Malawi, a small, impoverished country in southeast Africa has some of the worst child health indicators in the world. Among the major child health problems in this country is undernutrition. The present prospective, population-based, cohort study was performed to describe typical growth patterns and occurrence and determinants of undernutrition in under 3-year-old children in rural Malawi.

Compared to the international growth reference children in Lungwena were born lighter and shorter. The deficit in growth persisted until 24 months of age and there was no catch up growth. By 36 months of age, the children were 2.3kg lighter and 10.5 cm shorter compared to the reference. Faltering in linear growth was already marked at birth while weight faltering appeared at about 3 months of age.

The growth faltering resulted in high prevalence of undernutrition such that at peak levels, up to 70%, 40%, and 6% of the children were moderately stunted, underweight and wasted respectively. The incidence of undernutrition fluctuated according to season. This seasonal pattern was also reflected in weight and height gain whereby periods of best linear growth gain consistently lagged periods of best weight gain by about 3 months after infancy. Such a temporal relationship between weight gain and linear growth was, however, not documented at the individual level.

To study the determinants of incidence of undernutrition, multivariable models of various forms of undernutrition were constructed. Among the studied correlates of undernutrition, size at birth, maternal HIV, infant morbidity and access to health care independently predicted the occurrence of undernutrition.

The high prevalence of moderate undernutrition in the present study necessitated evaluation of the options for management of moderate undernutrition. In Malawi this typically involved dietary supplementation with a micronutrient-fortified maize / soy flour blend (Likuni Phala) whose effectiveness in promoting growth has been questioned. Apart from its nutrient quality, supplement leakage to non-intended beneficiaries and replacement of the beneficiary's usual dietary intake were some of the problems associated with this food. The present study tested an energy dense, micronutrient-fortified, peanut based spread called Ready to use food (RTUF) on moderately underweight and stunted 3 to 4 year old children. RTUF supplementation resulted in higher energy and nutrient intakes and less replacement compared to maize / soy flour. However RTUF did not prevent leakage. Both supplements modestly improved weight gain but did not promote height gain.

In conclusion, children in rural Malawi showed early growth faltering with no catch up growth. Prevention of undernutrition in this population should start prenatally and continue until after the second year of life. Such interventions, among others, should target reducing intrauterine growth retardation, HIV, and infant morbidity, and improving access to health care. However, effect of season should be taken into account when planning interventions. New strategies for dietary supplementation of moderately undernourished children, such as the use of energy dense spreads, should be evaluated. Preventing child undernutrition in this population may, however, take several generations, as the described growth pattern could also be familial.

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LIST OF ORIGINAL ARTICLES

The dissertation is based on the following original papers, referred to in the text by their roman numerals **I-IV**.

- I.** Maleta K, Virtanen SM, Espo M, Kulmala T and Ashorn P. Timing of growth faltering in rural Malawi. *Arch Dis Child*. In press.
- II.** Maleta K, Virtanen SM, Espo M, Kulmala T and Ashorn P. Malnutrition and its determinants in rural Malawi. *Paediatr Perinat Epidemiol*. In press
- III.** Maleta K, Virtanen SM, Espo M, Kulmala T and Ashorn P. Seasonality and the relationship between weight and height gain in rural Malawi. *Acta Paediatrica*. In press
- IV.** Maleta K, Kuittinen J, Duggan MB, Briend A, Manary M, Wales J, Kulmala T, and Ashorn P. Supplementary feeding of underweight, stunted rural Malawian children with a ready-to-use food. Submitted for publication.

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ABBREVIATIONS

ACC/SCN	Administrative Committee on Coordination/Sub-Committee on Nutrition.
AIDS	Acquired immunodeficiency virus
BCG	Bacillus Calmette-Guerin vaccine against tuberculosis
BMI	Body Mass Index
CDC	United States Centers for Disease Control
DPT	Vaccine against Diphtheria, Pertussis and Tetanus
GDP	Gross Domestic Product
GOBI-FFF	A United Nations Children's Fund (UNICEF) programme focusing on growth monitoring, oral rehydration, breastfeeding and immunisation of children and family planning, female education, and food supplementation.
HAZ	Height for age Z score
HIV	Human Immunodeficiency Virus
LAZ	Length for age Z score
MUAC	Mid upper arm circumference
NCHS	United States National Center for Health Statistics
RDA	Recommended Dietary Allowance
RTUF	Ready to use food
UNICEF	United Nations Children's Fund
WAZ	Weight for age Z score
WHZ	Weight for height Z score
WLZ	Weight for length Z score

1. INTRODUCTION

Undernutrition, defined as insufficient intake and utilisation of nutrients to meet an individual's needs to maintain good health, is a very big problem in the developing world. Up to a third of the children in the developing world are undernourished (de Onis et al. 1993). Undernutrition puts children at increased risk of morbidity, delayed mental and motor development and mortality. In fact, it has been estimated that up to half of the childhood deaths in the developing world are attributable to being underweight (Pelletier et al. 1994).

The two main forms of undernutrition are: Protein-energy undernutrition and specific micronutrient deficiency e.g. vitamin A deficiency. In public health, protein-energy undernutrition is assessed using measures of physical status. The main measures used are weight, and height or length related to age. Inadequate dietary intake and disease are the main causes of undernutrition. However, other factors such as water and sanitation, maternal and child care practices, food security, politics etc. influence the immediate causes and thus, are indirect causes of undernutrition.

Worldwide trends in undernutrition show a general pattern of decreasing prevalence (de Onis et al. 2000). However, the pattern has not been universal. Sub-Saharan Africa, with prevalence of undernutrition only surpassed by Asia, has shown the slowest decrease in prevalence in the world. In fact, the prevalence of undernutrition has been increasing in this region since the mid 1980s (ACC/SCN 2000). The prevalence of wasting, stunting and underweight in sub-Saharan Africa is estimated at 7.2%, 27%, and 39% re-

spectively (UNICEF 1998). Similar numbers for Malawi, the setting of the present study, are 7%, 30%, and 49% for wasting, underweight and stunting respectively (Malawi National Statistical Office 2001).

There is a wealth of data on undernutrition, its determinants and prevention that has been reviewed by several authors (Waterlow 1992, Waterlow and Schurch 1993, Black and Michaelsen 2002). However, undernutrition still remains a big problem in the developing world. Part of the reason is that some areas of the subject are still unclear. Issues such as the timing of growth faltering in developing countries (Rivera et al. 1997, Shrimpton et al. 2001) and the appropriateness of comparing exclusively breast fed infants to the currently used international growth reference (WHO working group on infant growth 1995, de Onis et al. 1997, Victora et al. 1998, Garza and de Onis 1999) still attract debate. The epidemiology of different forms of undernutrition also suggests that there may be differences in the aetiology of the various forms of undernutrition (Victora 1991, de Onis et al. 2000).

Prevention and treatment of undernutrition typically targets the causes of undernutrition either singly or in combination. The commonest approach is dietary supplementation. While institutional therapeutic feeding strategies have been well developed (WHO 1999), strategies for community level treatment of moderate undernutrition are not well developed. This is despite the fact that the majority of undernourished children are of the moderate forms that require community-based management.

Traditionally cereal /legume blends have been promoted for supplementation programs in sub-Saharan Africa (Brown et al. 1998). Their efficacy in controlled situations is however questionable (Beaton and Ghassemi 1982, Brown et al. 1998, ACC/SCN, 2001a). More recent strategies such as the use of spreads (Briend et al. 1999) need to be explored.

The present population-based prospective longitudinal cohort study was performed to describe typical growth among a population of rural Malawian children. Of special interest were the timing of growth faltering, occurrence and determinants of undernutrition and the potential of using a novel ready to use food supplement for the community treatment of under-nutrition.

2. LITERATURE REVIEW

The present study was a community-based investigation of typical growth and occurrence and determinants of undernutrition in under-five-year-old children. As such, the literature review focuses on the epidemiology of undernutrition. Main areas of emphasis are the definition, anthropometric classification, causes, consequences, and preventive strategies for undernutrition, and management of moderate undernutrition. The review restricts to post-natal undernutrition up to 5 years of age and concentrates on protein-energy undernutrition. Other aspects of undernutrition e.g. clinical and biochemical aspects, specific nutrient deficiencies and prenatal under-nutrition etc. will be alluded to but not discussed in detail. The last part of the review highlights some gaps in the current understanding of undernutrition, which form the basis of the current study.

2.1 Definition of undernutrition

Undernutrition is defined variably by different people. In international health literature, the term is often used synonymously with malnutrition, traditionally in reference to a situation where an individual has insufficient intake of protein and energy (total calories)(Rice et al. 2001). The term malnutrition, however, denotes both overnutrition and undernutrition. Other terms used include protein-energy malnutrition and protein-calorie malnutrition. The importance of micronutrients and the fact that deficiency in total energy often co-

total energy often co-exists with micronutrient deficiency, has led to preference for a neutral term such as undernutrition. Put simply, undernutrition can be defined as insufficient intake and utilisation of energy and nutrients to meet an individual's needs to maintain good health.

2.2 Measures of nutritional status

Several indicators are used to measure nutritional status. These include body composition, clinical signs of deficiency, physical function, biochemical compounds, metabolic processes or dietary intake. The choice of which of these indicators is used is dependent on the question being asked. In community studies of protein-energy undernutrition, body size is widely used because it is readily measurable and is a sensitive indicator of nutritional status and health. However, for specific nutrient deficiencies other indicators are used. For example serum retinol level, a biochemical measure, can be used to measure vitamin A deficiency and a clinical feature e.g. xerophthalmia can also be used as a measure of vitamin A deficiency.

The commonly used anthropometric measures are weight and length / height in combination with age and sex. For length / height, supine length is measured until 24 months and erect height thereafter because children are able to stand on their own. These measurements are used to construct

indices and indicators* that are used to describe nutritional status of individuals or populations. Other measures of body composition that are used include various body circumferences (mid upper arm, head, chest, abdomen etc) and skin folds (biceps, triceps, sub-scapular etc).

The three basic indices are: weight for age Z score (WAZ), length / height for age Z score (LAZ / HAZ) and weight for length / height Z score (WLZ / WHZ).

- Weight for age: defined as weight of a child relative to the weight of a child of the same age in a reference population, expressed either as a Z score[†] or a percentage relative to the median of the reference population. Qualitatively children who have low weight for age are described as being 'underweight'.
- Height for age (/ length for age): defined as height or length of a child relative to the length or height of a child of the same age in a reference population, expressed either as a Z score or a percentage relative to the median of the reference population. Qualitatively children who have low height for age are described as being 'stunted'.
- Weight for height (/ weight for length): defined as weight of a child relative to the weight of a child of

the same height or length in a reference population, expressed either as a Z score or a percentage relative to the median of the reference population. Qualitatively children who have low weight for height are described as being 'wasted'. Wasting is also sometimes called global undernutrition.

2.3 Anthropometric classification of undernutrition

Historically undernutrition was classified in terms of the clinical syndromes of Marasmus and Kwashiorkor (table 1)(Morley, 1994). The two syndromes were generally thought to represent two distinct syndromes, but as understanding of their aetiology advanced, it was realised that they represented extremes of the concept now called undernutrition. This fact led to the realisation that there were more children at the community level who had milder forms of nutritional deficiencies who did not develop overt marasmus or kwashiorkor but who still had adverse outcomes, a situation aptly described as the silent emergency by UNICEF (UNICEF 1998).

* Indices are defined as combinations of measurements, which have a biological meaning, e.g. weight for height while indicators are derived from indices to form a social concept taking on a value system e.g. proportion of children below a certain level of weight for height which can be used to describe nutritional status of a community (Waterlow et al. 1976)

[†] A Z score is a measure of how far an observation is from the population mean as measured in standard deviation units. A standard deviation score of a nutritional indicator for an individual = (individual's value - median value of reference population) / standard deviation value of reference population.

Table 1. Clinical features of marasmus and kwashiorkor.

Marasmus	Kwashiorkor
Extremely low weight	Oedema of the legs and arms and face
Extreme wasting	Moon face
Old persons face	Moderately low weight
Pot belly	Wasted muscles
Irritability and fretfulness	Misery and apathy
Hunger	Poor appetite
	Pale thin peeling skin
	Pale sparse hair with weak roots
	Hepatomegally

The use of a qualitative classification was however, not ideal for community studies and the clinical features denoting marasmus and kwashiorkor were not standardised. It was in this setting that the Gomez classification (Gomez et al. 1956)(table 2), based on weight for age was introduced. Its main criticism has been that it does not distinguish low weight for age from weight loss or from short stature. However, weight for age is highly correlated to height for age hence when used, low weight for age picks up both children who are underweight and those who are stunted (Golden 1996, p. 1278). Furthermore, weight is relatively easier to measure than height as such the Gomez classification is still widely used in public health settings.

Because the Gomez classification was primarily designed for community studies, there was still need to have a standardised classification system for undernutrition at the individual and clinical level. The Wellcome classification (Wellcome working party 1976) (Table 3) was introduced to meet this need. It was based on weight for age and presence or absence

and presence or absence of oedema. However, the disadvantage was that children classified as marasmic included children with low weight for age who were just stunted but of normal body proportions, and wasted children. Despite this, it remains useful in clinical practice.

The Waterlow classification (Waterlow 1976)(table 4), based on measuring both weight and height was introduced to overcome the misclassification highlighted above. It is currently the most commonly used classification in both clinical and community research settings. Apart from overcoming the earlier deficiencies, it also avoids the need for using qualitative terms such as kwashiorkor and marasmus. Apart from research and clinical use, widespread community use is hampered by the problems of making accurate height measurements. Furthermore, Z scores are also a difficult concept to explain to, and use by lower cadres of health care providers who are entrusted with screening for growth faltering.

Table 2. Gomez classification of undernutrition

Height for age	(Weight of subject / Weight of normal child of the same age) x 100
90% – 110%*	normal
75% – 89%	Grade 1 mild malnutrition
60% – 74%	Grade 2 moderate malnutrition
< 60%	Grade 3 severe malnutrition

* Percent of the Harvard reference

Table 3. Wellcome classification of undernutrition

Weight for age	No oedema	With oedema
60% - 80%*	Undernutrition	Kwashiorkor
< 60 %	Marasmus	Marasmic kwashiorkor

* percentage of the median WHO / NCHS reference

Table 4. Waterlow classification of undernutrition

		Normal	Mild*	Moderate*	Severe*
Weight for height (wasting)	% ⁺ Z score	90 - 120 2.0 to -0.99	80 - 89 -1.0 to -1.99	70 -79 -2.0 to -2.99	< 70% < -3.0
Height for age (stunting)	% Z score	95 - 110 2.0 to -0.99	90 - 94 -1.0 to -1.99	85 - 89 -2.0 to -2.99	< 85 < -3.0

* Without oedema. Presence of oedema denotes severe malnutrition (kwashiorkor) even without severe wasting (marasmus). ⁺ Percentage of the median WHO / NCHS reference.

Other classifications of undernutrition include mid upper arm circumference (MUAC). This is used based on the fact that mid upper arm circumference does not change much between 1 and 5 years of age, thus giving a measure which is almost independent of age (Waterlow 1976). It was especially useful in rapid assessments e.g. in emergencies because of its ease of use. Another measure that is becoming increasingly useful is body mass index (BMI), which is defined as weight (in kg) divided by the square of height (in metres). It is more commonly used in adults although it is also increasingly being used in children.

The foregoing classifications of undernutrition are dependent on a reference standard, the choice of which has generated a lot of debate. Previously the growth reference often used was the Harvard reference standard from the United States. This was superseded by the 1977 United States National Center for Health Statistics (NCHS) standard (Hamill et al. 1977), later adopted by the World Health organisation (Waterlow et al. 1977). However, there have been several criticisms of the WHO / NCHS reference standard.

Since the WHO / NCHS standard is based on largely bottle fed, affluent white children from a restricted area in

the United States (Kuczmarski, 2002) some people have argued that it does not adequately represent the target growth of children from developing countries, the majority of whom became classified as malnourished using this standard. However, studies have shown that affluent children from developing countries grow according to the reference (Habicht et al. 1974, Janes et al. 1981, Martorell et al. 1985, Malawi government 1991). Furthermore, children adopted or migrating from deprived environments of the developing countries to affluent environments have growth similar to that of the reference children (Martorell et al. 1985, Martorell et al. 1994). These observations justified the use of the NCHS standard for international comparisons.

Since its adoption further criticisms have been raised about the WHO / NCHS reference. First, concerns have arisen about the technical aspects of its construction in terms of centile smoothing procedures and estimation of extreme centiles (Dibley et al. 1987; Kuczmarski 2002). Secondly, the reference was based on two data sets, which led to discrepancies in the transition from length to height at 24 months, resulting in discontinuity in the length centiles at 24 months (Kuczmarski 2002). Thirdly, it has become apparent that exclusively breast-fed children grow differently to the largely bottle fed children of the current reference standards (WHO working group on infant growth 1995, de Onis et al. 1997, Dewey 1998, Victora et al. 1998, Garza and de Onis 1999). Based on these criticisms, studies are underway to construct a new international growth reference standard based on an internationally representative sample of children fed according to current WHO recommendations (de Onis et al. 1997, Garza and de Onis 1999).

2.4 Epidemiology of undernutrition

Primary malnutrition is usually a disease of the dependent (Golden 1996). The vulnerable groups include children in utero and within the first 5 years of life, adolescents, pregnant women and the elderly. Because children are completely dependent on others for their nutrition they are especially vulnerable.

Within the first 5 years of life there are critical periods during which undernutrition occurs, and evidence suggest that this is different for the various forms of undernutrition. In most developing countries underweight and wasting tend to become evident between 4 and 6 months while stunting tends to appear as early as 2-3 months of age (Habicht et al. 1974, Whitehead and Paul 1984, Martorell 1985, Martorell et al. 1994, Neuman and Harrison 1994, Rivera et al. 1997, Shrimpton et al. 2001). The period of highest incidence of undernutrition is between 6 and 20 months, a period Mata (1991) has described as 'the valley of death', because of the high mortality during this period.

Several reasons have been proposed for the observed high incidence of undernutrition during this period. The period coincides with the introduction of complementary feeding as breast milk becomes insufficient to meet the metabolic needs of the growing child. However, the complementary feeds in most developing countries are less energy dense and unhygienic, resulting in reduced energy and nutrient intake and increased morbidity (especially diarrhoea), which leads to undernutrition (Morley et al. 1968, Scrimshaw et al. 1968, Martorell et al.

1975, Mata 1978). Furthermore, during this period children are becoming more

Table 5. Regional prevalence of undernutrition in children aged less than 5 years.

	<u>% Underweight</u>	<u>% Stunted</u>	<u>% Wasted</u>
Asia	42 (154)	47 (173)	11 (40)
Africa	27 (32)	39 (45)	7 (8)
<i>Malawi*</i>	30.0	49.0	7.0
Latin America	12 (7)	22 (12)	3 (2)
Oceania	29(0.3)	42 (0.4)	6 (0.1)

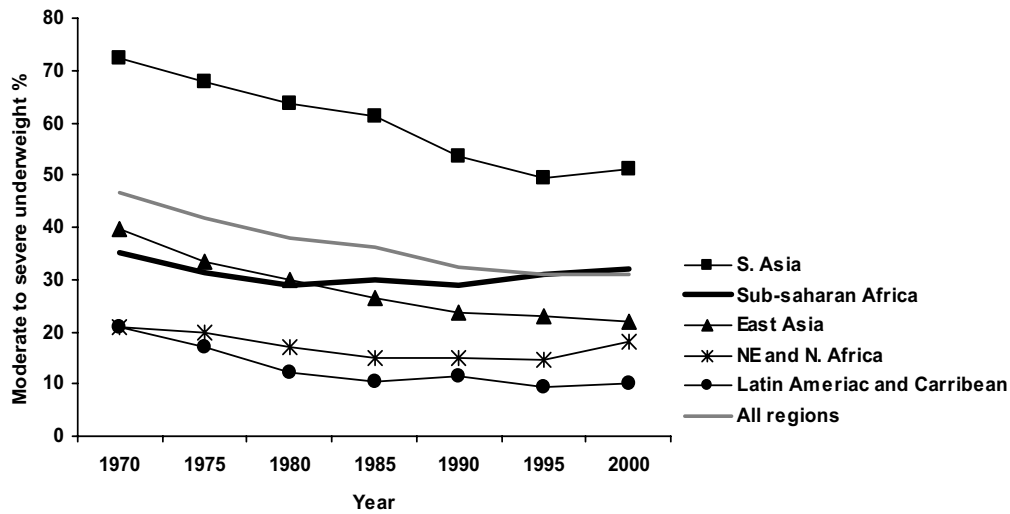
Figures in parenthesis represent absolute numbers of children in millions
*Source de Onis et al. 2000. *Source UNICEF. 2002.*

mobile and thus exposed to infections while at the same time the protection they had from maternal antibodies has waned and this leads to increased infectious diseases and ultimately to undernutrition. While childhood undernutrition occurs everywhere in the world the majority of the affected children are found in the developing world. Table 5 shows the regional distribution of under-five-year-old undernutrition in the developing world.

One hundred and sixty seven million children in the developing world are classified as malnourished representing 33% of all children in the developing world (de Onis et al. 2000). As shown in table 5, Asia has the highest prevalence of all forms of undernutrition, followed by Africa while Latin America has the lowest prevalence.

Despite the picture presented by the aggregate figures, there is a lot of heterogeneity within the regions with some countries having high and others low prevalence. Worldwide there have been impressive improvements in the reduction of undernutrition, but some regions have lagged behind. Evidence suggests the rate of improvement is decreasing while in some regions the prevalence is actually increasing (ACC/SCN 2000). Figure 1 shows the regional trends of undernutrition (moderate to severe underweight) from 1970 to 2000. South Asia has shown the most improvement while sub-Saharan Africa has shown the lowest decrease, and since 1985 the prevalence of underweight has been increasing in sub-Saharan Africa.

Figure 1: Trends of prevalence of underweight under-five-year-olds from 1970 to 2000.



Graph based on figures from Smith and Hadaad, 2001 (1970 to 1995) and ACC/SCN 2000. (2000)

Some of the improvements in prevalence of undernutrition have been attributed to improvements in national economies, especially in Asia, which has led to improvements in water and sanitation, per capita food availability, and maternal literacy and women's social status. Sub-Saharan Africa on the other hand has shown decline in its economy as evidenced by reduction in per capita gross domestic product (GDP) by USD52 between 1985 and 1995 (Ramalingaswami et al. 1996, Smith and Hadaad 2001,). This has led to increased poverty, stagnation in improvements in water and sanitation and female literacy (Smith and Hadaad 2001). Another factor that may explain the situation in sub-Saharan Africa is the impact of HIV/AIDS on undernutrition and national economies (Ramalingaswami et al. 1996, ACC-/SCN 2001b).

Despite improvements in the above correlates of undernutrition, which in Asia are better than sub-Saharan Africa, undernutrition still remains a bigger problem in Asia relative to sub-Saharan Africa. Ramalingaswami and

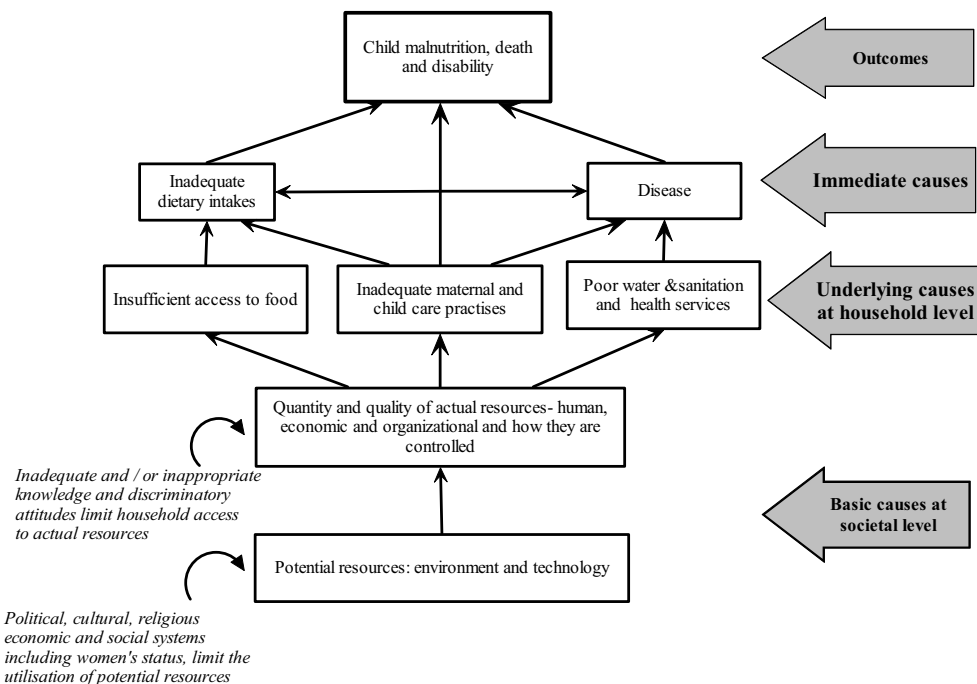
co-workers (1996) describe this as the so-called Asian enigma[‡]. Part of their explanation is the low social status of women in Asia compared to Africa. However, this may not explain the whole picture, and it has been suggested that the determinants of malnutrition may differ from country to country or they may have different strength in different environments (Smith and Haddad 2001).

Another intriguing observation is the finding that some regions with high prevalence of stunting have relatively low prevalence of wasting e.g. Sub-Saharan Africa, while in Asia wasting and stunting are correlated (Victora 1991). One explanation for this is that it denotes possible differences in etiology of stunting and wasting (Victora, 1991). Post and Victora (2001) and Martorell (2001) explain this observation as being partly due to differences in body proportions. This brings into

[‡] Asian enigma refers to the situation whereby despite improvements in the correlates of malnutrition in Asia such as per capita food availability, female education, water and sanitation, undernutrition remains a very big problem.

question the appropriateness of current growth reference standards for comparison of children across different regions if there are differences in body habitus.

Figure 2. Conceptual diagram of the determinants of undernutrition.



Source State of the Worlds Children 1998, UNICEF 1998

2.5 Determinants of undernutrition

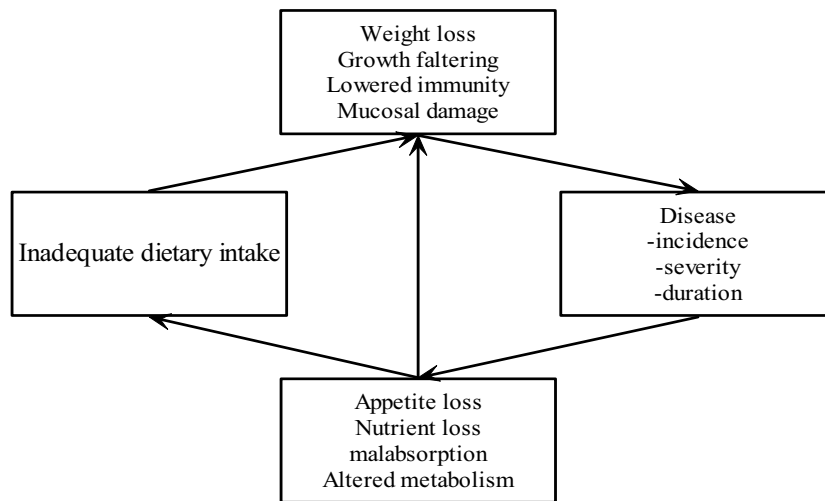
The determinants of malnutrition are multiple, inter-related and operate at different levels. The causes and their relationships can concisely be diagrammatically presented as shown in figure 2.

There are three levels of causes of undernutrition. Immediate causes operating at the individual level, underlying causes operating at the household

level, and basic causes which operate at the society level. The immediate causes of malnutrition inter-relate with malnutrition in such a way that they form a vicious cycle which if not broken results in death (Figure 3).

Many observational studies on the relationship of undernutrition and infectious disease have been done and have been extensively reviewed (Scrimshaw et al. 1968, Martorell et al. 1975, Tomkins and Watson, 1989, Baqui and Black 2002).

Figure 3. Undernutrition and disease vicious cycle.



Source: *State of the Worlds Children 1998, UNICEF 1998*

Malnourished children are more prone to frequent, long lasting, and severe episodes of disease that result in reduced dietary intakes due to reduction in appetite, nutrient loss, malabsorption, and altered metabolism. The reduced dietary intake leads to further undernutrition thereby completing the cycle which starts again and if unbroken may quickly lead to death (Tomkins and Watson 1989).

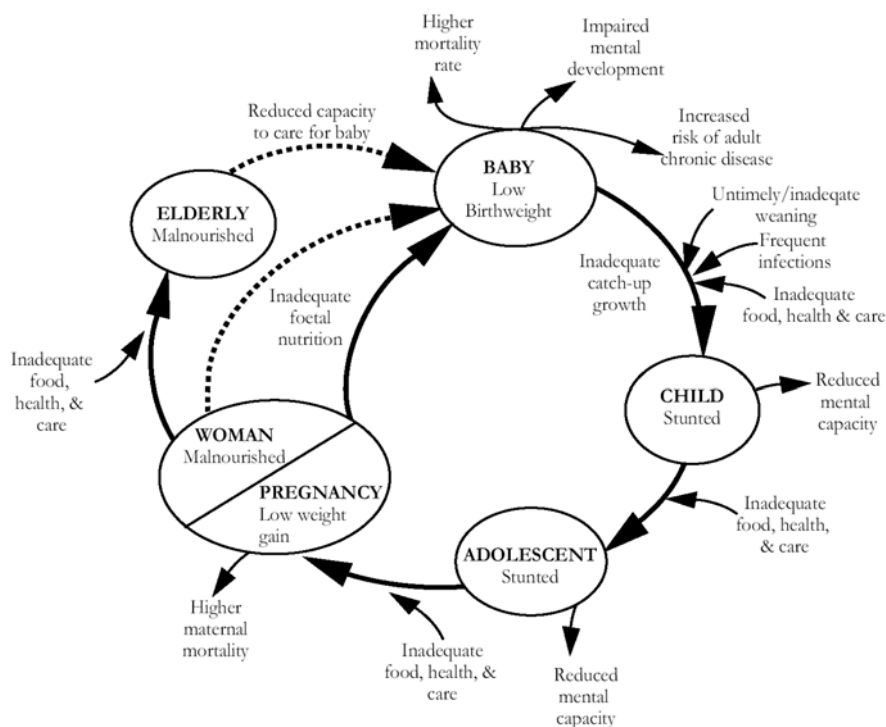
At the family level, the immediate causes of undernutrition are in turn caused by such factors as inadequate access to safe water and sanitation, inadequate maternal and childcare practices and insufficient access to food. At the societal level, these are determined by the quantity and quality of actual resources (human, economic and organisational) and how they are controlled. Other factors such as social, political, cultural and religious factors limit how these potential resources are turned into actual resources (UNICEF 1998).

Another important determinant of undernutrition, which deserves special mention, is the HIV/AIDS pandemic. Over 36 million people are living with HIV/AIDS and of these 95% are in de-

veloping countries. In sub-Saharan Africa up to 26 million people are infected with HIV / AIDS (ACC/SCN 2001b).

There are several ways how HIV could result in undernutrition. First, there are direct effects on the infected child whereby HIV like other infections increases metabolic demand and because of immunosuppression predisposes to opportunistic infections e.g. diarrhoea, which results in undernutrition. Secondly, there are indirect effects on the child through effects of HIV on mothers irrespective of whether a child is infected or not. Maternal HIV could result in reduced care and disruption of feeding due to maternal morbidity or death. Thirdly, because HIV is transmitted from mother to child also through breastfeeding, it complicates choices for infant feeding in developing countries. Children who are not breastfed are at increased risk of undernutrition and yet breastfeeding may also increase mother to child transmission of HIV. Recent evidence however suggests that exclusive breastfeeding could be protective against mother to child transmission (Coutsoudis 1999, Coutsooudis 2001).

Figure 4: Undernutrition throughout the lifecycle.



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Despite this, exclusive breast-feeding is very difficult to achieve in most developing countries. Another impact of HIV, which could lead to undernutrition, is its effect in reducing food and economic security of the family and society through loss of economically active members of the family or society and diversion of already scarce resources (ACC/SCN 2001b).

2.6 Consequences of undernutrition

Undernutrition results in both immediate and long-term consequences. Figure 4 succinctly shows the effects of undernutrition throughout the lifecycle. Undernutrition in utero leads to low birth weight babies who are prone to morbidity, have higher risk of cognitive and mental impairment and mor-

tality (Ashworth 1998). Low birth-weight babies may also end up as undernourished toddlers with reduced mental capacity (Pollit and Oh 1994, Grantham-McGregor 1995). Childhood undernutrition could also lead to stunted adolescents who may end up as stunted adults if there is no catch up growth.

Childhood undernutrition has been implicated in up to 50 % of all childhood deaths in the developing world (Pelletier et al. 1995). It has also been associated with adulthood chronic diseases such as diabetes mellitus, hypertension and coronary heart diseases, the so-called ‘foetal origins’ hypothesis[§] (Barker, 1995; Joseph, 2002).

[§] The foetal origins hypothesis states that adverse influences in early life, as manifested by poor growth *in utero* and in the immediate postnatal period, cause metabolic or physiologic ‘programming’ that leads to a higher risk of various chronic diseases.

Childhood under-nutrition, leading to undernourished adults, could also lead to reduced physical capacity, which may be disadvantageous economically in environments heavily dependent on manual labour as exist in developing countries (Branca et al. 1993). Furthermore, in women this may lead to obstetric complications that could lead to increase in maternal and child mortality. Additionally, undernourished women are more likely to have low birth weight children, and thus the undernutrition cycle starts again and the effects of undernutrition end up spanning several generations if unchecked (ACC/SCN, 2001a).

2.7 Strategies for prevention of undernutrition

There are several strategies that have been employed for the prevention of undernutrition and they range from specific interventions aimed at specific determinants to general interventions aimed at a broad range of determinants. The range of interventions has been encapsulated in UNICEF's selective primary health care approach under the banner GOBI-FFF (growth monitoring, oral rehydration therapy for diarrhoeal disease, promotion of breastfeeding, childhood immunisations, female education, food supplements and fertility control).

In Malawi, where undernutrition is a very big problem and a significant contributor to child mortality, some of these strategies have been incorporated in a national programme of action for the survival, protection and development of children in the 1990's (Government of Malawi, 1991). Specific emphasis was put on strengthening and expanding growth monitoring activities, nutrition education programmes, improving food security, monitoring

infectious diseases, encouraging appropriate breastfeeding and complementary feeding practices, and maintaining the high levels of immunisation coverage. Some of the strategies for prevention of undernutrition are discussed below

2.7.1 Education

Female education is a major determinant of whether a child becomes malnourished or not. Countries with high female literacy and female status tend to have lower prevalence of malnutrition, independent of differences in the countries' wealth or general standards of living (UNICEF 1998). It is not clear how this relationship works. Some possible reasons include the fact that educated women are better at organising their resources and time, making better use of health services, start child bearing later and have longer birth intervals and likely to have an independent source of income (Waterlow 1993). However, education per se, if not coupled with improvement in the social status of women may not be effective. A possible reason being the fact that decision-making powers in a community may be vested in men, as such equipping women with knowledge may not necessarily translate into giving them with decision-making powers.

2.7.2 Child growth monitoring

This strategy is based on the longitudinal charting of a child's growth in order to identify when growth starts faltering and institute action to prevent development of undernutrition. Unlike anthropometric screening for interventions, there is no consensus what constitutes inadequate growth when action has to be taken as the risk from milder

forms of growth deficit is not well known (Jelliffe and Jelliffe, 1987). In any case, even if the level for taking action were agreed it is still not clear what action to take. Furthermore, since it is the lowest cadres of primary health care providers who usually carry out growth monitoring, it does not necessarily result in proper action. This is because it is difficult to make accurate measurements and interpret them to take necessary action. Compounding this is the fact that the people entrusted with this activity in primary health care programs have many other things to do making the charting of growth an automatic task that does not result in proper action. However, others have argued that when placed in the hands of villagers, growth monitoring becomes a tool for development and community participation (Hendratta and Rohde 1988).

2.7.3 Water supply and sanitation

Reductions in diarrhoeal morbidity and mortality of about 27 % and 30 % respectively have been reported following improvements in water supply and disposal of excreta (Esrey et al. 1985). However, it has been questioned whether this reduction in morbidity does lead to improvements in nutritional status.

A study done in Bangladesh showed that despite reduction of about 30% in diarrhoea morbidity following improvements in water supply and excreta disposal and hygiene education, there was no improvement in nutritional status (Briend et al. 1989). Similarly in the Gambia, improvements in water and sanitation and reduction in diarrhoeal morbidity did not result in improvement in growth (Rowland et al. 1977). However, although the direct effects of improved water and sanitation on growth are debatable, it is still

assumed that the decreased incidence of diarrhoeal disease on its own reduces the risk of development of malnutrition by reducing the frequency of infections and time spent being ill.

2.7.4 Control of diarrhoeal disease

Diarrhoea has a consistent harmful effect on weight gain. A review of the effect of diarrhoea on undernutrition reports that between 10 to 80% of the difference between the international growth reference and growth of children in developing countries is associated with diarrhoeal disease. The effect on height gain though reported by some studies, has not been consistent (Baqui and Black et al. 2002). However, other studies have queried whether the effect of diarrhoea on undernutrition is overemphasized (Briend et al. 1990). The reason for this assertion being that the effect of diarrhoea on dietary intake and growth is transient and thus a child could return to normal diet and growth within a few weeks of an illness episode. However, in the developing world children tend to have frequent episodes of diarrhoea such that they do not have sufficient time to recover to their pre-illness nutritional status. This puts them on a slippery slope to undernutrition whereby each sub-sequent episode of diarrhoea pushes them down the slope.

In terms of aetiology, pathogens causing chronic and persistent diarrhoea are the most commonly implicated e.g. enterotoxigenic *E. coli*, *Shigella* and *cryptosporidium*. Strategies to prevent diarrhoea through, for example, exclusive breast-feeding, improved water and sanitation, treatment and promotion of oral rehydration therapy are thought to mitigate against undernutrition.

2.7.5 Immunisations

Of the vaccine preventable diseases, measles is the one most associated with undernutrition. However, its effect on growth has had mixed results. Poor growth outcomes have been reported in some studies (Reddy et al. 1986) and no effect has been reported in others (Rowland et al. 1977). Measles is thought to cause undernutrition through the following mechanisms. First, measles infection is followed by a period of depressed cell mediated immunity, which makes children susceptible to opportunistic infections including diarrhoea and acute respiratory infections. Secondly, during measles infection energy intake is reduced (Duggan et al. 1986). The infections and reduced dietary intake predispose children to undernutrition. Immunisation against measles could thus prevent children from developing undernutrition.

2.7.6 Promotion of breastfeeding

Promotion of breast-feeding is a strategy that has been encouraged to prevent development of undernutrition. In developing countries, exclusive breast-feeding for at least 4 months is promoted to prevent development of undernutrition. Exclusively bottle fed infants in the developing world have a risk ratio of developing undernutrition of between 2 to 50 fold compared to exclusively breast fed infants (Jason et al. 1984). Breast-feeding has also been shown to reduce the risk of morbidity especially diarrhoeal disease. Recent evidence also suggests that exclusive breast-feeding could reduce mother to child transmission of HIV, which in turn reduces the risk of undernutrition (Coutsoudis et al. 1994, Coutsooudis et al. 1999). However, questions still remain on how long exclusive breast-

feeding should be encouraged but current WHO recommendations is 6 months (WHO, 2001). In Malawi, the setting of the present study the recommendation is to exclusively breastfeed for 4 to 6 months.

2.7.7 Supplementary feeding

Supplementary feeding is one of the commonest approaches to management of undernutrition. It has been used for both prevention and treatment of undernutrition. In controlled re-search situations supplementary feeding has been shown to improve growth of undernourished children.

During pregnancy, dietary supplementation with balanced energy and protein has been shown to improve pregnancy weight gain and birth size (de Onis et al. 1998). Similarly in children, supplementary feeding has been associated with improvements in weight and height gain in controlled situations (Mora et al. 1981, Gershoff et al. 1988, Lutter et al. 1990, Hussaini et al. 1991, Martorell et al. 1994, Schroeder et al. 1995, Simondon et al. 1996; Lartey et al. 1999). The improvements in growth have however been more pronounced in children less than 2 years and have depended on the severity of undernutrition (Lutter et al. 1990, Schroeder et al. 1995). This has been attributed to the fact that growth rates and incidence of undernutrition are highest in under-2-year-old children. As such, the often-short dietary supplementation interventions are likely to show effect on growth during such periods of high growth rates. Not all supplementary feeding studies have however, shown improvements in growth. In a study in amongst children aged between 4 to 7 months old in four countries (Congo, Bolivia, New Caledonia and Senegal) a micro-nutrient fortified maize / soy supplementation

trial did not result in statistically significant improvement in weight gain nor height gain except in one country where there was a significant improvement in height gain among supplemented children compared to control children (Simondon et al. 1996).

Despite some impressive results in controlled situations, large-scale supplementary feeding programs have not shown much success in improving childhood growth (Beaton and Ghassemi 1982, Brown et al. 1998, ACC/SCN 2001a). Some of the problems associated with large scale feeding programs have been problems in targeting the right groups, ensuring intake of the supplement by intended beneficiaries, spillover to other than intended beneficiaries and replacement of the habitual dietary intakes of the beneficiaries (Beaton and Ghassemi 1982). Another additional important issue is also the choice of food supplements to use.

Provision of food supplements is however, just one of the approaches to improve dietary intake of children. Other strategies include nutrition education targeted at families to enhance appropriate feeding behaviours and improve energy and nutrient density of local foods. Unlike food supplement provision, this is relatively cheap as it relies on local solutions and can easily be sustainable. However, it requires behavioural change that is difficult to achieve. Furthermore, the limited diversity of many developing country diets may make it difficult to correct some micronutrient deficiencies with such an approach. Training of educators also increases the cost of this approach (Dewey 2001). Another approach at the societal or national level is fortification of foodstuffs to correct specific micronutrient deficiencies e.g. salt iodisation. However, these approaches have the problems of cost, dependency, sustainability and

bioavailability. A cost-benefit analysis is always important in choosing which approach to implement.

Other strategies used to prevent undernutrition include mass treatment of specific diseases e.g. deworming programs for intestinal parasites, or treatment of schistosomiasis to prevent anaemia.

2.8 Management of moderate undernutrition

The epidemiology of moderate undernutrition is such that it precludes an institutional approach. As such, moderate undernutrition is usually managed at the community level and a major component of the management strategy is dietary supplementation. Other elements such as infection treatment and nutrition education are also included.

In terms of dietary supplementation there are no standard regimens as in therapeutic feeding for severe undernutrition, for which standardised regimens have been developed (WHO 1999). However a common approach in Sub-Saharan Africa is the use of cereal / legume blends (Harper and Jansen 1985, Dijkhuisen 2001). In Malawi, the cereal / legume blend used is an 80%: 20% maize / soy blend which is either provided without micronutrient fortification or sometimes fortified with micronutrients. When provided unfortified the general advice has been to encourage caregivers to add oil and egg to increase energy density and improve nutrient content respectively.

The use of cereal / legume blends though promoted has resulted in mixed results in terms of impact on growth (Brown et al. 1998, Dewey 2002). In Guatemala, cereal / legume based supplementation during pregnancy and childhood resulted in improved weight and height gain in children less than

three years old. In older children the effect was less marked (Martorell et al. 1994, Schroeder et al. 1995). In another study, no improvement in weight and height gain was reported among 4 to 7 month-old children (Simondon 1996). In Ghana a fortified cereal / legume complementary food was no more effective at improving weight and height than an improved local weaning food, 'koko' (Lartey et al. 1999). This raises the question about the effectiveness of current policy of supplementing moderately undernourished under-5-year-old children with cereal legume blends.

There are several reasons for the mixed results with cereal / legume blends. They have low energy density making them voluminous and thus likely to result in replacement of habitual intakes of beneficiaries. Their similarity to staples makes them easily acceptable but also make them easily diverted to other family members (Beaton and Ghassemi, 1982). Furthermore since they have to be made up into porridge every time they are used, they are labour and resource intensive resulting in further strain on already poor households. Although their nutrient content can be improved by micronutrient fortification and energy density by adding oil, this is not always possible in poor communities and the unfortified food may sometimes be no better than the usual staples.

Recently Briend and co-workers (1999) reported use of a peanut based, energy dense micronutrient fortified spread called Ready to use Food (RTUF) in therapeutic feeding of severely malnourished children. RTUF has the advantage of good storage properties, which reduces risk of contamination, making it potentially valuable in contaminated environments of the developing world. Another advantage is that it does not need further processing before eating thus can eas-

ily be eaten in between meals as a snack. The high energy density makes it less voluminous and thus reduces risk of replacement of the beneficiary's usual dietary intakes and also increases chances of improved energy intake and weight gain (Stubbs et al. 2000, Yao and Roberts 2001). To date it has successfully been used in therapeutic feeding (Briend et al. 1999, Collins 2002) and in emergency relief situations (Collins 2001). The use of such a spread would offer a possibility for community management of undernutrition. It has however, not yet been tried in community settings and no studies have been conducted to determine whether it is culturally acceptable in rural communities.

2.9 Justification for the present study

The literature review revealed that undernutrition remains a very big problem in most of the developing world especially sub-Saharan Africa. The trend whereby the gains made in the late 1970s and early 1980s has now been substituted by increasing prevalence since the late 1980s is especially worrying. The general economic downturn in the region has largely been blamed for this observation. Malawi, which is one of the poorest countries in the world, has poor health and nutritional indicators sometimes only surpassed by countries under conflict. Such a situation necessitated a search for local causes of under-nutrition, which heavily contribute to childhood mortality in Malawi.

The literature review also showed that certain aspects of undernutrition have not been wholly explained. The determination of when growth faltering starts has been hampered by lack of an appropriate reference standard. This

raised the question when growth faltering actually started, as preventive strategies have to be instituted early in the development of the problem. For this local studies were needed especially in Malawi where the problem of undernutrition is very big.

The review highlighted the fact that determinants of malnutrition may not have the same importance in all settings and thus preventive strategies that work in one place may not work in all settings. This meant that determination of local causes and effective interventions was one way of alleviating the problem. It has been standard to consider underweight and stunting as being resultant from the same causal factors. The epidemiology of wasting and stunting and the relationship of weight and height gain suggested possible difference in aetiology and a need to develop a clear understanding of their

relationship, which in turn may help in developing effective interventions.

The magnitude of undernutrition in Malawi necessitated a community approach to the management of the problem. The choices for community management were however not well developed. In searching for determinants and preventive strategies, it is also important to develop strategies for managing those children who already suffer from undernutrition. To date the strategies used for community management of malnutrition in Malawi have largely been based on maize / soy supplementation, the effectiveness of which has not been fully established in controlled situations. The fact that the magnitude of the problem has not improved is probably because current methods may not be effective and reason enough to explore new strategies.

3. AIMS

The aim of the present study was to describe typical growth pattern of children, analyse occurrence and determinants of undernutrition and evaluate a community based nutritional intervention for malnourished children. The specific objectives were:

1. To describe the typical pattern of growth of under 3 year old children (I).
2. To analyse the incidence and determinants of malnutrition in under 3 year old children (II).
3. To describe the effect of season on growth and the relationship between weight and height gain in under 3 year old children (III).
4. To analyse whether supplementation with Ready to Use Food (RTUF) would improve dietary intakes and short-term growth of moderately under-nourished 3 to 4 year old children. (IV).

4. METHODS

4.1 Study setting and subjects

4.1.1. Study Area

The study was done in Lungwena, southern Malawi. Malawi itself is a small southeast African country with a population of 11 million inhabitants (figure 5). The country was one of the 10 to 20 least developed countries in the world with a per capita gross domestic product (GDP) of 170 USD (UNICEF 2002). Of the economically active population, 83% were involved in agriculture and 73% were subsistence farmers producing almost all the

food they ate on small land holdings (Malawi national Statistical Office 2000). Of the population, 85% lived in rural areas. Climatically there were three seasons: a rainy season between December and April, a cool dry season between May and August and a dry hot season between September and December. The staple food was maize for most of the country although cassava and rice were also widely eaten in the northern part of Malawi. Table 6 shows some of the important health, socio-economic and demographic indicators for Malawi.

Figure 5. Map of Africa showing location of the study area

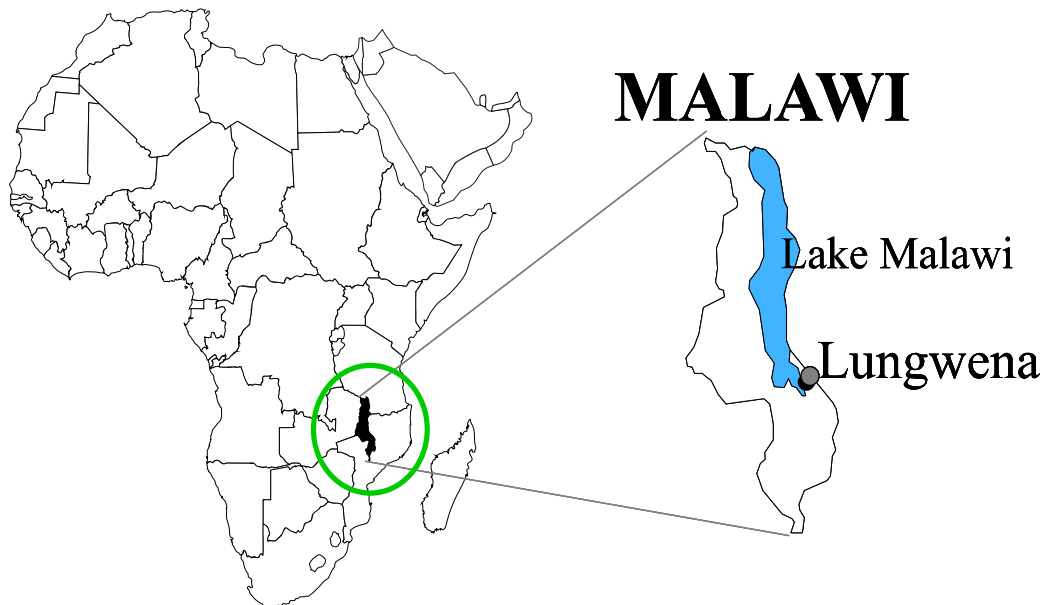


Table 6. Basic demographic and health indicators for Malawi

Indicator	Measure
Total Land area	94, 276 km ²
Total population	10.3 million
Population density	105 / km ²
Urbanisation rate	15%
Per capita gross domestic product per capita (USD)	170 (1997)
Maternal mortality ratio	1120/100,000
Female literacy rate	42%
Male literacy rate	72%
Life expectancy at birth	39 years
Infant mortality rate	134 / 1000
Under five mortality rate	234 / 1000
Immunisation coverage (by 12 months of age)	
BCG	90%
Polio	73%
Diphtheria, Pertusis, Tetanus (DPT)	79%
Measles	64%

Source: Malawi Demographic and health Survey 2000 and UNICEF State of the Worlds Children 2002.

The fieldwork of the study was done in Lungwena, a rural community on the eastern shore of lake Malawi in Mangochi district southern Malawi. The study area, which was a catchment area of a public health centre, was a 20km long by 5 km wide area about 30km from the nearest town Mangochi. There were 23 villages and population of 17000 people in 4200 households. Islam was the predominant religion and the population belonged to the Yao ethnic group, with Chiyao as the main language although Chichewa, the national language, was also widely spoken. Subsistence farming for maize and fishing formed the main economic activity in the area. Maize, grown between December and March was the main staple food. Other crops grown in the area included cassava, sweet potato, beans, and assorted vegetables.

The Lungwena health centre provided free preventive and curative ser-

vices e.g. family planning, antenatal and delivery services, growth monitoring, vaccinations and treatment of common illnesses. Primary health care was also provided through regular outreach clinics and a network of health surveillance assistants and trained traditional birth attendants in the villages. During a local 1994 demographic and health survey, it was found that health indicators for this community were below the national average. To improve the health situation in the area, the Lungwena Child Survival Study, a population-based longitudinal cohort study of maternal and child health was started. The current analysis used data from this larger prospective study.

4.1.2 Study subjects

The study subjects were members of the Lungwena child survival study

cohort. The cohort comprised live born children of mothers who attended antenatal clinic at Lungwena health centre between June 1995 and September 1996. Mothers were recruited in mid pregnancy at first booking for antenatal care at the health centre. Background data and maternal health characteristics were collected at enrolment and during the pregnancy follow up. Their live born children formed the cohort, which has been intensively followed up from birth until 5 years of age. Due to a very high enrolment and participation rate, the children represented 95% of all children born in the area during the enrolment period. The subjects for the nutrition intervention (IV) were a subset of children still being followed up in the child survival study as of August 2000 who were identified as malnourished.

4.2 Data collection

4.2.1 Follow up

The children were seen as soon as possible after birth at the health centre during which information on delivery events and anthropometric measurements were collected and a clinical examination was done. From 1 month until 18 months trained research assistants visited the children in their homes once a month to collect information on morbidity, feeding, development, mortality, and anthropometric measurements. From 18 months until 60 months, the home visits were done at 3-month intervals and information was collected on development and anthropometric measurements taken. The follow up is schematically presented in figure 6. The analysis for papers I to III is restricted to the period from birth until 36 months of age. For paper IV

malnourished 3 to 4 year old children still in follow up as of August 2000 were recruited.

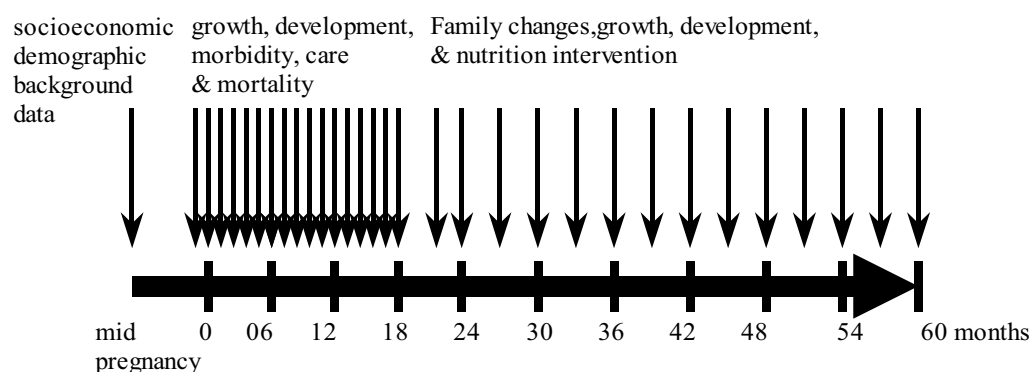
4.2.2 Background and maternal characteristics data

Data on the socio-economic background of the participants was collected through personal interviews using structured questionnaires at enrolment. Agricultural extension workers estimated cultivated farm areas. Laboratory investigations for human immunodeficiency virus (HIV) infection (Enzyme linked immunosorbent assay (ELISA) antibody test), syphilis reactivity (Rapid plasma reagin, RPR test), malaria (peripheral blood parasitaemia), anaemia (haematocrit < 0.34), were done at antenatal enrolment. Maternal anthropometry (weight and height), gestational length (fundal height palpation) and dietary intakes were collected during antenatal follow up. Delivery events and child characteristics were recorded as soon as possible after birth. Detailed descriptions of the methods have been described elsewhere (Kulmala et al., 2001a).

4.2.3 Infant feeding, morbidity, development and mortality

Data on infant feeding, morbidity, and development was collected through personal interviews using structured questionnaires administered by trained research assistants in the participants homes during the regular follow up visits. Feeding data included information on range of foods given to the child, length of breastfeeding, and complementary feeding. Morbidity information collected included diarrhoea, ARI and malaria. After any illness episode, a health seeking behaviour

Figure 6. Follow up of study participants.



questionnaire was also administered. Child development was assessed by achievement of developmental milestones including sitting, crawling, standing, walking and talking. Mortality information was collected using a verbal autopsy validated earlier for use in the area (Nykanen et al. 1995). All this information was supplemented with data obtained from health centre records. Detailed descriptions and definitions have been described elsewhere (Vaahtera et al. 2000a).

4.2.4 Anthropometric measurements

Eight trained research assistants made home-visits to collect anthropometric measurements at monthly intervals from birth up to the age of 18 months and at 3-month intervals thereafter. Weight was measured with a spring scale (reading increments 100 g) until the age of 12 months. Thereafter it was measured with a battery operated digital bathroom scale (100 g increments). Length / height and mid-upper arm circumference (MUAC) were measured with locally constructed length / height boards and non-elastic tape measures, having reading increments of 5 mm,

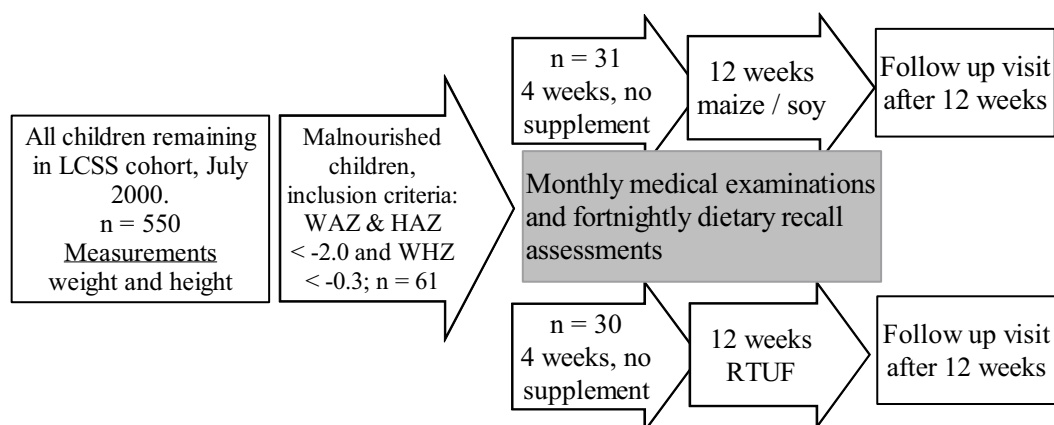
and 1 mm, respectively. For length / height, the children were measured supine until they were able to stand and erect thereafter. Scales and length / height boards were checked and calibrated regularly with internal standards. To verify data accuracy, a random sample of 5-10% of the measurements was taken twice by two independent research assistants.

4.2.5 Nutrition Intervention study

All the children from the LCSS cohort identified as malnourished in August 2000 were recruited for the nutrition intervention study. The children were randomised to receive one of two food supplements: A novel peanut based fortified energy dense spread called Ready to use Food (RTUF) or Likuni phala, a 80%: 20% mix of maize/soy flour. The follow up was divided into three phases: In the first phase, lasting 4 weeks, the children were assessed for growth and dietary intakes without food supplementation. During the next 12 weeks on top of the usual follow up the children received either maize / soy flour or RTUF providing them with approximately 2MJ of energy daily. Thereafter there was a 12-week post-

supplementation follow-up visit. The set up and follow up of the study is schematically shown in figure 7.

Figure 7. Follow up of subjects during the nutrition intervention



Although the two supplements provided similar amounts of energy, there were major differences in their micronutrient content (Table 1 / IV). Comprehensive medical examinations were done before entry and at four weekly intervals until the end of the supplementation period. The study physician carried out the examinations at the health centre. Dietary 24-hour recall assessments were done at fortnightly intervals from start of the study up to the end of the supplementation period.

Anthropometric measurements collected were weight and height. One observer (the author of this thesis) did all the measurements at 4-weekly intervals. Weights was measured with an electronic scale (SECA 834, Chasmors Ltd, London, UK) and recorded to the nearest 10 g, heights with a portable stadiometer (Harpenden stadiometer, Holtain Ltd, UK) recorded to the nearest 1 mm. A standard error of measurement was established at the start

and end of the project by replicate, blinded measurements of each anthropometric variable in 10 children of the same age and growth characteristics as the study group.

Assessment of dietary intake was done by trained local research assistants, using a structured inter-active 24-hour recall method (Ferguson 1995). The method had previously been used to quantify dietary intakes amongst pregnant women in Lungwena and amongst 3-5-year-old children elsewhere in Malawi (Ferguson et al. 1995, Ndekha et al. 2000). The method was pre-tested before the study. During study period, dietary information was collected on 24-hour intakes at 14-day intervals until the end of the supplementation period. The participating household was forewarned and supplied with a picture chart illustrating local foods, which would serve as a checklist and in which the guardians would mark foods eaten during the study day. The carers were also ad-

vised to feed the participant child from an individual plate on the day of the study.

The process involved four stages: All foods consumed during the previous day were first listed, using the pictorial food calendar. Details, like cooking method and ingredients of composite dishes were then discussed with the cook and recorded. Next, the amount consumed at a given meal was estimated, and finally the entire 24hour recall was reviewed. The estimate of portion size consumed was improved by the use of graded food models, and salted replicas (e.g. of nsima, relish or phala) from which the mother took a duplicate 'serving' which was then weighed by the interviewer.

4.3 Statistical approach

Data entry was done with Microsoft Excel 7.0 while analysis was done mainly using SPSS 10.0 statistical software. Anthropometric indices were calculated with EPI-INFO 6.04b software, using the World Health Organisation (WHO) adopted 1977 National

Center for Health Statistics (NCHS) reference population (WHO 1983). The LMS program (Cole and Huigi 2002) was used for drawing smoothed growth curves (I), and SAS PC software v. 8.0 (SAS/STAT software; SAS Institute, Cary, NC) was used for modelling determinants of growth (III). Calculation of the dietary intake of selected nutrients was done using a self-made programme installed on a Microsoft EXCEL 7.0 spreadsheet, using food composition data from the World Food Dietary Assessment Program (FAO 2000) (IV). Detailed statistical methods are found in the individual papers.

4.4 Ethical approval

The Malawi National Health Sciences Research Committee approved the research protocol for the Lungwena Child Survival Study (LCSS). University of Malawi, College of Medicine Research Committee, approved the research protocol for the nutrition intervention.

5. RESULTS

5.1 Enrolment and follow up

Of 799 women who attended ANC clinic at Lungwena health centre, two were found to be not pregnant and two

dropped out during pregnancy. The remaining women produced 813 foetuses of which there were 4 abortions, 38 stillbirths and 18 sets of twins. A total of 13,728 home visits were done of which 38 (0.3%) were excluded because of questionable data quality. The flow of the subjects during the follow up is shown in figure 8 and their baseline characteristics in table 7.

Figure 8. Flow of subjects through the growth study.

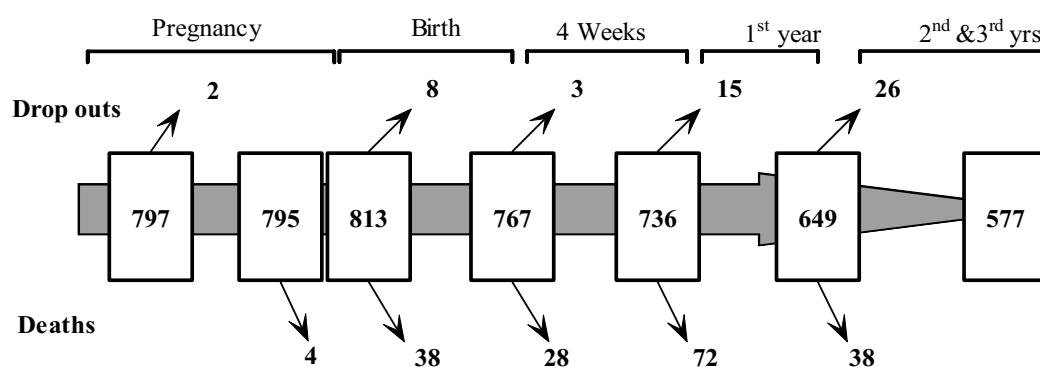


Table 7. Background characteristics of study participants

Variable	Prevalence (%)	Number of Observations
Maternal characteristics		
Maternal age < 20 years	22	794
Mother illiterate	86	789
Mother HIV positive	19	782
Mother primiparous	24	795
Maternal height < 150cm	16	778
Delivery attended by trained assistant	40	795
Socio-demographic characteristics		
Livestock ownership (cattle, goats or chickens)	50	795
House with more than one room	15	795
Family owns mattress, radio, bike or car	46	795
Family has safe water source	36	795
Family has latrine	76	795
Cultivated land area > 0.5 hectares	37	795
Distance to health centre >5km	50	795
Child characteristics		
Preterm delivery	21	782
Low birth weight	15	476
Sex ratio (male: female)	1.05: 1.00	767
Mean (SD) birth weight (kg)	3.1(0.5)	476

5.2 Growth pattern and timing of growth faltering (I)

Children in Lungwena were born on average 510 g lighter and 2.5 cm shorter compared to the children of the 2000 CDC growth reference (figure 9a and 9b). In the first 2 months of age, children in Lungwena gained more weight compared to the reference children such that by 3 months the Lungwena median weight centile was almost at the same level as the reference median centile. Between 3 and 18 months, the rate of weight gain in Lungwena was consistently lower compared to the reference. After 18 months of age weight gain in Lungwena was comparable to the reference. The faltering in weight gain resulted in progressive deviation of the Lungwena median weight centile away from the

reference median during the first year. After infancy, the Lungwena median weight centile paralleled the reference third centile. By 36 months, the faltering in weight gain accounted for a mean weight deficit of 2.3 kg.

Height gain on the other hand was already lower at birth compared to the reference and did not show any catch up during the first 3 years. The difference in height gain was big initially but decreased progressively. In the third year height gain in Lungwena was almost similar to the reference. By 3 years of age, the children in Lungwena were 10.5 cm shorter compared to the reference children. When analysed separately for boys and girls, boys were in general heavier and longer at birth and remained so throughout the first 3 years. The difference was however, not very big (results not shown).

Figure 9 a. Weight gain of children in Lungwena compared to the 2000 US CDC growth reference.

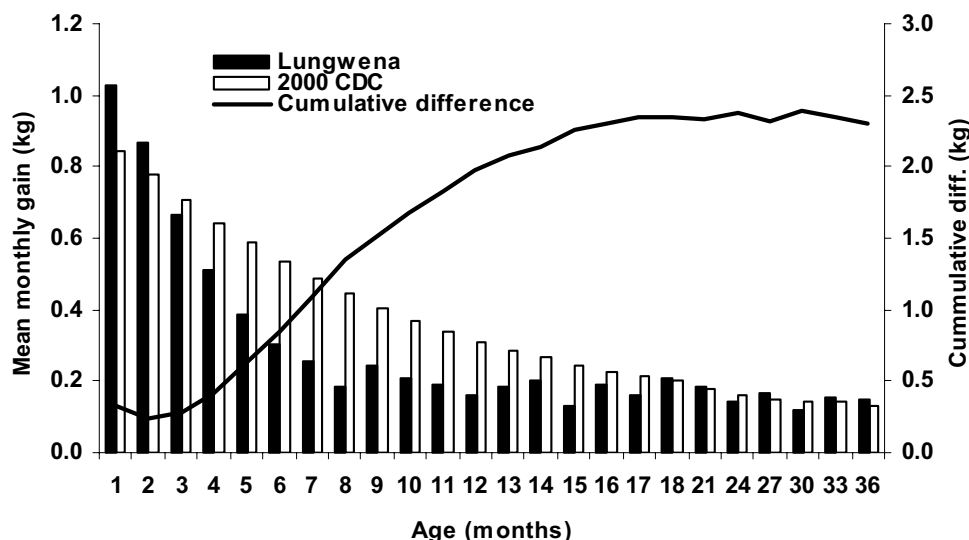
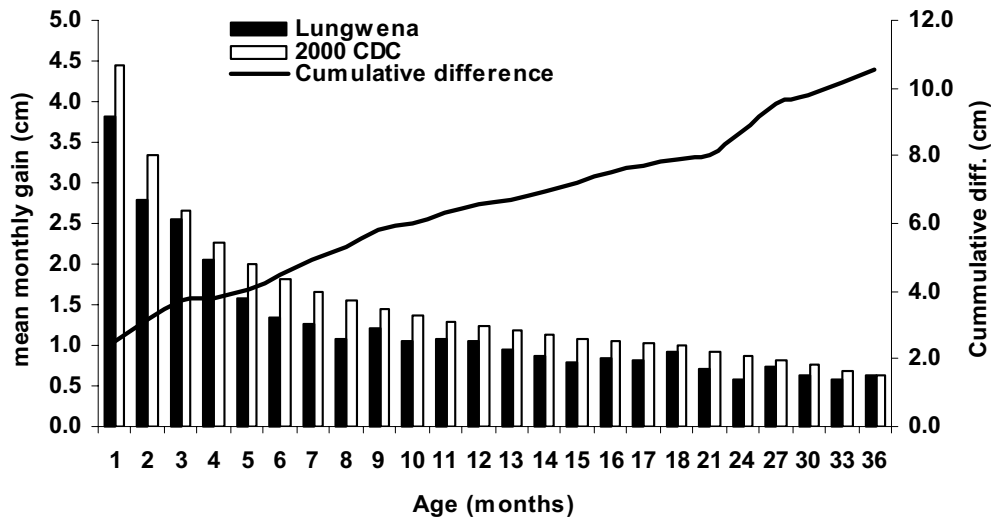


Figure 9 b. Height gains of children in Lungwena compared to the 2000 US CDC growth reference.



5.3 Incidence and determinants of undernutrition (II)

Childhood undernutrition was very common in Lungwena. At peak levels, 40% of the children were moderately underweight, 70% moderately stunted and 6% moderately wasted. Periods of peak incidence of undernutrition were 6 and 18 months for wasting and underweight while stunting occurred mostly between 3 and 12 months. After the second year of life, incidence of stunting was rare while wasting was fairly common (Figure 1 in II).

To identify predictors of moderate wasting, severe underweight and severe stunting, multivariable modelling with lifetable survival regression methods using complementary log-log modelling was used. Some 165 (22%) children developed moderate wasting, 216 (28%) developed severe underweight and 516 (67%) developed severe stunting during the 36 months of follow up. Variables evaluated for as-

sociation to undernutrition included socio-economic factors (water and sanitation, distance to the health centre, livestock possession, type of housing and parental literacy), maternal factors (BMI, HIV status, pregnancy weight gain, and place of delivery), and child factors (sex, gestation age, birth size, feeding characteristics and morbidity). In univariable analysis, only small size during the first 3 months of age, high morbidity in infancy, positive maternal HIV test, long distance to health facility, home delivery, preterm birth and male sex were significantly associated with undernutrition at the 0.1 level.

Three multivariable models were built to model the independent predictors of severe underweight, severe stunting and moderate wasting. Only variables that had significant association with the outcomes at the 0.1 level were included in the models. Severe underweight was predicted by high

morbidity in infancy (> 2.4 episodes/month) and long distance to the health centre, RR (95% C.I), 2.2[1.4, 3.4] and 1.6 [1.0, 2.6] respectively. Small size during the first 3 months predicted the occurrence of severe stunting and moderate wasting, RR (95% C.I) 2.1 [1.3, 3.4] and 2.0 [1.1, 3.5], respectively. Moderate wasting was further predicted by high morbidity in infancy, and maternal HIV, RR (95% C.I) 2.3 [1.5, 3.5] and 1.6 [1.0, 2.6] respectively. Subgroup analysis among children whose birth-weight data was available (n = 230) resulted in largely similar results, although with reduced power.

Among the studied variables, socio-economic status and infant feeding duration were not associated with undernutrition in the present analysis.

5.4 Seasonality of growth (III)

To determine the effect of season on growth we analysed the changes in weight and height gain and the occurrence of malnutrition according to season. Weight and height gain followed a clear seasonal pattern that was age dependent. During the first 6 months of age, high weight and height gain occurred at the same time between June and July while the period between December and April was one of low weight and height gain. Anthropometric indices also followed a similar pattern. Between 7 and 12 months of age, the pattern was less clear with a lot of fluctuation although May and June appeared to be months of high weight and height gain.

Post infancy, the seasonal pattern became more obvious and differed between weight and height. Weight gain was highest between May and July, and lowest between December and January. Height gains on the other

hand were highest between August and October and lowest between March and April. Weight for age Z score gain and Weight for height Z score gain followed a seasonal pattern similar to weight gain while height for age Z score gain followed a seasonal pattern similar to height gain. The prevalence of undernutrition followed a similar seasonal pattern with high prevalence of underweight and stunting occurring after a few months of minimal weight and height gain respectively. The seasonal pattern was most marked for wasting, where for example; the prevalence was about 6% in March but less than 3% in August. For underweight and stunting which were very prevalent, there was less seasonal fluctuation after infancy.

The population level temporal relationship of height gain lagging weight gain by about 3 months was further examined on an individual level by a series of Pearson's correlation analyses in 3-month age intervals. Height gain in any interval was not correlated to weight gain in the previous interval unlike the population level pattern above. However height gain was directly correlated to weight for height gain in the previous interval, weight for height at the start of height gain and concurrent weight gain. The amount of correlation ranged from 0.14 to 0.40.

When the above variables were controlled for each other in partial correlation analysis, height gain was only directly correlated to concurrent weight gain and weight for height at the start of height gain. Up to 16% of the variation in height gain could be explained by variation in weight gain in the same interval and up to 14% of the variation in height gain could be explained by variation in weight for height Z score at start of height gain.

To explore the relationship of weight for height Z score to height gain, a similar analysis as above was

done. Weight for height Z score at any point was directly correlated to weight gain and weight for height Z score gain in the preceding interval but inversely correlated to height gain in the previous interval. In partial correlation analysis, weight for height Z score at any point was only directly correlated by weight gain in the previous interval. Preceding weight gain accounted for up to 38% of the variation in weight for height Z score at any point. This suggested that the relationship between weight gain and height gain in succeeding age intervals was indirect. Instead weight gain influenced weight for height gain, which in turn influenced height gain. Generally, similar results were obtained when the analysis was based on individual 3-month seasons (January-March, April-June, July-September and October-December).

5.5 Supplementary feeding of moderately undernourished children with Ready to use Food (IV)

From 555 children still in LCSS follow up in August 2000, 61 moderately underweight and stunted children were enrolled for the nutrition intervention. At baseline, their average age was 52 months, mean weight was 12.5kg and height 91cm. The average weight for height, weight for age and height for age Z scores were 0.9, 2.5 and 3.0 respectively. Thirty-one children were allocated to receive maize / soy flour while 30 children received RTUF. All children completed the follow up. Their anthropometric and dietary characteristics were comparable at baseline (Table 2 in IV). All children except one child in the RTUF group accepted the dietary supplements. There were no reported adverse reactions. From 24-hour dietary recall assessment, 30%

(28 / 92 g) of the distributed RTUF and 43% (60 / 140 g) of the maize / soy flour was actually consumed by the study participants. This translated into average energy supplementation of 150kcal and 215kcal for RTUF and maize / soy groups respectively.

Compared to baseline, mean nutrient intakes during supplementation were higher among the RTUF group compared to the maize / soy group. Except for Vitamin A and C, whose intake was strongly affected by mangoes and green vegetables coming into season, children receiving maize / soy did not show significant improvement in nutrient intakes.

Children receiving RTUF received on average daily 550KJ more energy, 11g more fat, 2.3mg more iron and 3.2mg more zinc compared to those receiving maize / soy flour. The intakes of protein, carbohydrates, calcium, and vitamin A and C were roughly similar. More children receiving RTUF achieved their recommended dietary allowances for the selected nutrients compared to children receiving maize / soy flour. When sources of dietary intake were compared, part of the difference in nutrient intakes was explained by reduced intakes of staples among maize / soy group compared to the RTUF group.

In terms of growth, both supplements modestly improved weight gain but did not promote height gain. Children receiving RTUF gained 99g / month compared to maize / soy supplemented children who gained 83g / month. After supplementation weight gain among children who received RTUF continued to be greater compared to maize / soy supplemented children.

6. DISCUSSION

The present community based prospective cohort study aimed at describing the typical growth patterns of under-3-year old children in rural Malawi. Of special interest was to determine critical periods for growth faltering and determinants of under-nutrition. Furthermore, since it was evident from our results on growth patterns that moderate undernutrition was the biggest problem in this community, we also tested a novel food supplement for moderately under-nourished children. The following section discusses the possible reasons for the observed results. The final section discusses the strengths and limitations of the study. The main findings are discussed in the order of the aims.

6.1 Growth pattern and timing of growth faltering (I)

Children in Lungwena were born small and showed very little if any catch up growth relative to the WHO growth reference. The critical period for growth faltering appeared to be between 3 and 24 months. The finding of early growth faltering in the present population is similar to those of other studies from the developing countries (Whitehead and Paul 1984, Martorell 1994, Neuman and Harrison 1994). However, our finding of shorter mean birth lengths is different from other studies in the region (Neuman and Harrison 1994).

There are several reasons that could explain the described growth pattern. First, children in Lungwena

were predominantly breast fed, though not exclusively breastfed by WHO definition. As such, the pattern of growth of apparent weight faltering from about 3 months could reflect normal growth pattern of breast fed children. Exclusively breastfed children tend to have higher growth rates in the first 3 months compared to the WHO reference. Thereafter they show weight faltering throughout infancy before growing at the same rate as the reference children after 12 months of age (WHO 1995, Dewey 1998, Victora et al. 1998). This observation has largely been attributed to the inappropriateness of the current growth reference, which is based on largely bottle fed children. To overcome the technical inadequacies of the current reference, growth of children in Lungwena was also compared to the technically superior 2000 CDC growth reference (Kuczmarski et al. 2000). The results however, remained the same.

Secondly, the period of growth faltering in this population coincided with the period of introduction of complementary feeding and increasing morbidity from infectious diseases. In Malawi, like in other developing countries, complementary feeding was introduced very early (Vaahtera et al. 2001). Furthermore, the feeds that are used are usually of low energy density and unhygienic resulting in reduced dietary intakes and increased infections, which together increases the risk of undernutrition. Exacerbating the above points is the fact that children at this time have less protection from inherited maternal immunity while their immunity is still developing, and they

are becoming more mobile thus exposing themselves to infections in the unhygienic environment.

A third possible explanation for the growth pattern observed in the present study population is that it could well be familial. Mean adult female was 155 cm. Male adult height was not available but in a similar population in Malawi it was 162cm (Pelletier et al. 1991). As such, it is possible that the centile shift shown by the children was a normal physiological shift to follow a familial pattern. This assertion is enhanced by the observation that the initial period of growth faltering between 3 and 24 months was followed by a period of growth, which was equivalent to that of the reference children. The pattern is, however, unlikely to be genetic, as affluent Malawian children have been shown to have growth patterns similar to the reference population (Malawi government. 1991). The fact that children from developing countries have growth similar to the reference in 'ideal' environments has been documented before (Habicht et al. 1974, Janes et al. 1981, Martorell et al. 1994).

Three possible reasons could explain the small birth size documented in the present study: preterm deliveries, intra-uterine growth retardation, and maternal HIV. In the present population, the prevalence of preterm delivery was high at 22 % resulting in small birth size (Kulmala et al. 2001a). Furthermore, there was low energy intake and high frequency of malaria infection during pregnancy (Ndekha et al. 2000) that could have resulted in intrauterine growth retardation. In the present study length was more compromised compared to weight. This finding could suggest that growth retardation had already occurred even before the third trimester. In such a situation it has been suggested that not only lipid accumulation but also cellu-

lar synthesis is compromised hence such children, born short, do not show catch up postnatally (Milner, 1988). This is in keeping with our observations in the present study, which show no catch up growth. Lastly, maternal HIV, which was very widespread in the present population (18% seroprevalence among pregnant women), could also explain the small birth size. Small birth size and child growth faltering has been documented among children born to HIV positive women in Sub-Saharan Africa (Taha et al. 1995, Bailey et al. 1999). These three factors either singly or in conjunction could have caused the small birth size and contributed to the lack of catch up growth in this population.

Potentially our finding of short mean birth length could also be attributed to bias from a small sample size due to missing birth data from most of the participants. However, at 1 month, when data was available for most of the children, the length deficit persisted. This suggests that our finding represent a true situation in this population.

6.2 Incidence and determinants of malnutrition (II)

The present study documented a very big problem of undernutrition in this population. The critical period for development of undernutrition was between 3 and 24 months. Among the studied determinants of malnutrition, maternal HIV infection, home delivery, gestational length, size at birth, male sex and morbidity during infancy were associated with undernutrition in univariate analysis. None of the studied socio-economic variables and feeding patterns were associated with undernutrition. When controlled for other variables, maternal HIV, distance from

health centre, small size at birth and infant morbidity independently predicted the occurrence of undernutrition.

Several reasons could explain the findings above. The importance of morbidity in the causation of undernutrition has been well documented before (Scrimshaw et al. 1968, Tomkins and Watson 1989, Stephensen 1999, Baqui and Black 2002). In the present study, the period of peak incidence of undernutrition was also the period when prevalence of morbidity increases.

Morbidity causes undernutrition through reduced dietary intakes from reduced intake from nausea and appetite loss. It also increases metabolic demand, causes nutrient loss through diarrhoea and malabsorption which leads to inadequate dietary intakes and hence undernutrition. The period of peak incidence of undernutrition coincided with a period when complementary feeding was introduced and in the unhygienic environments of rural areas, this increased risk of morbidity especially diarrhoea and thus undernutrition. In the present study population, this risk was increased by poor adherence to breastfeeding and complementary feeding guidelines (Vaahtera et al. 2001).

Low birth weight is another well-known risk factor for undernutrition (Bakketig et al. 1998). In the present study with no obvious catch up growth, smaller children during the initial 3 months of life were likely to stay small and be at increased risk for undernutrition. Maternal HIV has also been documented as a cause undernutrition (ACC/SCN 2001). Maternal HIV could have caused undernutrition through its direct effects on the children, which include low birth weight and increased morbidity. Indirectly HIV could have caused undernutrition through its effects on the mother such as increased

maternal morbidity, disruption of feeding and childcare practices. The association between distance to the health centre and undernutrition could be explained by reduced modern health care seeking behaviour by families living far away from the health centre.

Other important factors normally associated with undernutrition e.g. length of breastfeeding and socio-economic factors were not found to be significant predictors of undernutrition in the present study. A possible explanation for this was lack of heterogeneity in feeding practices and socio-economic status to detect the importance of these factors. Furthermore, by modelling incidence rather than prevalence, we were more likely to pick out proximate causes rather than intermediate causes which are mediated through other factors. However, these factors still were important in this population. In an earlier analysis of determinants of prevalence of undernutrition in the same population, infant feeding practices and parental literacy independently predicted the prevalence of severe stunting at 12 months of age (Espo et al, 2002).

6.3 Seasonality of growth (III)

Childhood growth in Lungwena followed a seasonal pattern, which was age dependent. During the first year of life the seasonal pattern of weight and height gain was similar but after 12 months the seasonal pattern of weight and height gain was different. During the first 12 months of age, weight and height gain peaked at the same time while after 12 months height gain lagged weight gain by about 3 months. The incidence and prevalence of undernutrition followed a similar seasonal pattern. The population level temporal relationship of height gain

lagging weight gain by about 3 months was however not demonstrated at the individual level. Our results suggested that the relationship between weight and height gain was indirect and probably mediated through weight for height.

Such a pattern of height gain lagging weight gain by about 3 months has been previously described in developing countries (McGregor et al. 1968, Tomkins et al. 1986, Brown et al. 1982, Pollit et al. 1989, Costello 1989). Weight gain has been shown to peak in autumn and winter while height gain peaks in spring and summer (Gelander et al. 1994, Xu et al. 2001). The explanation for these findings has differed for developing and developed countries. In the developed countries, this has been partly attributed to changes in the light and dark cycle and its influence on physical activity and growth hormone production (Gelander et al. 1994). In the developing countries, seasonal variation in food availability and prevalence of infectious diseases seem a more plausible explanation (Brown et al. 1982, Nabarro et al. 1988, Costello 1989, Pollit et al. 1989).

The age dependent pattern could be explained by the growing child's increasing dependency on the external environment and its seasonal fluctuation. During the first 6 months although seasonality was present, it was tempered and modified because it was mediated through maternal health. After this, inadequacy of breast-feeding to meet the metabolic needs of the child and introduction of sub-optimal complementary foods made the children susceptible to the effects of season. This fact could explain the less clear pattern observed in infancy compared to the period after infancy. However, other studies have documented a seasonal pattern, which was not age dependent (Xu et al. 2001).

Another possible explanation for the age changing seasonal pattern of weight and height gain is that factors controlling weight gain and linear growth are different in infancy and childhood. For linear growth it has been hypothesized that linear growth in the first three years of age has two distinct phases: an infancy phase starting in utero and continuing with decelerating influence until about 3 years of age which is nutrition dependent and a childhood phase starting at about 6 to 12 months of age which is growth hormone driven (Kalberg et al. 1994). This could partly explain the observation that during infancy when the nutrition dependent infancy phase is strong maximal weight and height gain followed a seasonal pattern related to food availability and occurred at the same time. After infancy when height gain is largely under the influence of growth hormone, the seasonal pattern of linear growth did not coincide with the period of good food availability. In this period, other environmental factors such as the light and dark cycle and its influence on growth hormone production (Waterlow, 1994) and physical activity with its influence on bone growth (Golding, 1994) could have been more important than nutrition.

The indirect relationship between weight and height gain, which is probably dependent on weight for height level has been previously documented. In nutritional rehabilitation of malnourished children height gain has been shown to ensue only after a certain level of weight for height (Walker and Golden, 1989). In the present study, median weight for height was above the WHO reference in infancy and below it after infancy (Figure 1 in III). The pattern of height gain lagging weight gain was only evident after infancy, suggesting that the pattern depended on a possible level of

weight for height. Such a level of weight for height could not however be determined in this population.

It is also possible that the observed correlations represent a normal pattern of regression towards the mean (Davis, 1976) with children with higher weight and height gains at one point showing slower gains at the next interval. In summary, our results suggest that the factors controlling weight and height gain are not only different but also differ during infancy and childhood. This would imply differences in the aetiology of stunting and underweight and hence the need for different strategies in tackling the two problems. However, the amount of variation in height gain explained by the studied variables was quite low. This indicated that there were other variables not studied that could have played a role. Such factors that have been suggested to explain the variation in height gain include physical activity and social stimulation and other environmental factors e.g. temperature.

6.4 Supplementary feeding of moderately malnourished children with Ready to use Food (IV)

In the present study we documented improved nutrient intakes and weight gain following supplementation with RTUF. The improvements among children receiving maize / soy were less marked. Compared to maize / soy supplemented children, more children supplemented with RTUF achieved RDAs for selected nutrients. Maize / soy supplementation resulted in displacement of the children's habitual dietary intakes unlike RTUF which did not have this problem. However, the study subjects consumed only a small fraction of the provided food supplements.

Several reasons could explain the observed dietary intakes. RTUF was more likely to increase nutrient intakes because of its superior nutrient composition and nutrient density. High energy density food has been shown to improve nutrient intakes and weight gain in other situations (Stubbs et al. 2000, Yao and Roberts 2001). The high nutrient density and the fact that it could be eaten without further processing meant that it did not result in replacement of the children's usual diet. Maize / soy on the other hand had low energy density, thus, to achieve high nutrient intakes, there was need to consume larger amounts of it. Furthermore, maize / soy required that it be freshly prepared into porridge every time it was consumed. In the face of scarce resources (time, water, fuel wood etc), the factors above could have hampered frequent provision of the supplement to the children and resulted in replacement of the children's usual dietary intakes.

In terms of growth, both supplements had only modest effect on weight gain and did not promote linear growth. The fact that both supplements resulted in only a modest improvement in weight gain and no improvement in height gain could be due to the low uptake of both supplements. The lack of effect on height gain could also be because height gain follows weight gain, a fact shown in the present population (III) as well as in other populations (Brown 1982, Walker and Golden 1988, Costello 1989, Xu et al. 2001). The present intervention was too short to document an effect on height gain. Furthermore, effect of supplementation on growth depends on degree of growth deficit as well as age (Lutter et al. 1990, Schroeder et al 1995). The present study subjects were not only older but also not very malnourished thereby reducing their probability to show an effect on growth.

Despite close supervision, not all of the provided food supplements were consumed by the study subjects. This is likely to be due to sharing of the supplement to other than the intended beneficiaries. For maize / soy this could have been enhanced by its similarity to the main staple, maize. However, it is also possible that the food was consumed but not detected by our dietary recall assessments. The assessments were done at the end of a fortnightly supplementation period. As such, it is possible that the earlier rations in the two-week period were larger and the food had run out by the time of the assessments. However, the modest effect on growth supports the assertion that the food was shared.

6.5 Strengths and limitations of the study

The main strength of the study was its design. The population-based prospective cohort design allowed for accurate description of events of interest as well as cause and effect relationships. The cohort was assembled in a relatively closed community in terms of migration since the community was matrilineal and as such there was little migration of the study participants in case of marriage breakdown. There was a very high enrollment rate and active follow up ensured very minimal loss to follow up, which made our findings to be representative of the study population. Our findings could also reasonably well be generalized to the Malawian population, most of which live in rural areas not unlike the study population.

Another strength of the study was its ability to ensure community participation. The study was done within a setting of provision of primary health care through the Lungwena health centre. As such, the study was probably

perceived as an extension of primary health care. Community participation was enhanced by use of local research assistants and local resources wherever possible. Continuous re-training of the research assistants ensured collection of data of reasonable quality. Furthermore, having a random sample of the measurements repeated by a different research assistant ensured data quality. Through this approach we were able to detect an incident of data fabrication by one research assistant over a period of one month. This fabricated data was discarded and the affected 78 home visits treated as missed visits.

However despite the above strengths there were some limitations, which need to be borne in mind when interpreting the results.

In the present study population most of the women delivered at home resulting in that anthropometric data at birth was only available for one out of four of the study participants. This deficiency reduced the power of the study to make inferences on size at birth and its relation to outcomes of interest. Use of a proxy variable for birthweight and subgroup analysis were used to be able to make inferences about size at birth but our results may be biased by reduction in sample size (III).

Another problem with the description of typical growth was the way length / height was measured. In the present study children were measured supine until when able to stand erect when height was measured. Ideally this should have been standardized to be able to make necessary adjustments, which were impossible to do in this case because of no standardized procedure. As such our length/height data could affect our results when compared to the international standards, which specifically differentiate length from height. This could also have affected interpretation of seasonality as well as quantification of undernutrition.

The present study used recall method to collect data on morbidity and dietary intakes. The use of such method could have resulted in recall bias in the respective studies (III and IV). For dietary intakes analysis, the error was reduced by use of an interactive technique aided by pictorial calendar as prompts to improve recall. While it is well known that 24-hour dietary recall assessment biased on one day is not representative for an individual's usual diet due to high intra-individual variation in intake, the primary interest in the present study was group estimates, which can reliably be estimated by 24 hour recalls (Ferguson et al, 1995).

The design of the nutritional intervention also had some limitations. First the intervention was done in toddlers who were also not very undernourished and such children have previously been shown to be less responsive to supplementary feeding compared to younger children. This could have diluted the potential effect of the intervention. While the children represented our primary interest group and a convenient sample, for a study testing a relatively novel food, a more malnourished group would have been more desirable. The choice of toddlers was however, influenced by the fact that the food had never been tried in infants. Furthermore, the wasting criterion employed

in the present study was unconventional, and the results could have been different if done in moderately wasted children. However in the present population and age group, the children were very stunted and underweight such that moderate wasting was quite rare.

Many studies describing childhood growth in developing countries have been conducted before. As such, the present study might be considered repetitive of the earlier studies. However, not many well-conducted population based cohort studies have been done in the region. Furthermore, despite the earlier studies, Sub-Saharan Africa poses a special challenge considering the epidemiology of undernutrition in the region. Viewed in this background, the present study is necessary in terms of helping in formulating hypotheses for locally important issues in undernutrition. The nutrition intervention described here is a result of such hypothesis formulation. However, in concentrating on the population level associations, the study missed an opportunity to clarify some causality issues by not studying individual level factors through e.g. systematic clinical and laboratory investigations. In terms of undernutrition clinical and biochemical markers of specific nutrient deficiency would have helped clarify the problem of undernutrition in the present population.

7. KEY FINDINGS

Childhood growth faltering in the present population started very early. Weight gain faltering appeared at 3 months of age while height gain faltering was already present at birth. The critical period for growth faltering in this population was between 3 and 24 months. There was hardly any catch up growth exhibited by the children in relation to the international reference. However, the faltering shown in this population could well be familial and the development of a new international reference standard could change the interpretation of the present findings.

Small size at birth, prematurity, maternal HIV, infant morbidity and distance to the health centre and home deliveries significantly contributed to the development of undernutrition. There was little heterogeneity in infant feeding patterns and socio-economic factors to be able to separate their effects on undernutrition.

Growth in weight and height and the prevalence of undernutrition followed a seasonal pattern. Despite obvious relationship between weight gain and height gain at the population level, there was no temporal relationship at the individual level. There are other factors not studied which could have explained the variation in height gain. The factors controlling weight and height gain may be different in infancy and adulthood and hence the aetiology of stunting and underweight may be different

Supplementation of moderately stunted and underweight children with RTUF significantly improved dietary intakes compared to the usual supplement, maize / soy flour. However, the

effect on short-term growth was less marked. Community supplementation with an energy dense spread reduced the problem of 'replacement' but did not overcome the problem of sharing.

8 CONCLUSIONS AND POLICY IMPLICATIONS

The present study demonstrated that undernutrition was a very big problem in this community. The critical period of growth faltering and the pattern of incidence of under-nutrition suggested that preventive strategies should be targeted at the antenatal period and the first 2 years of life. From the pattern of growth, especially the timing of growth faltering and the relationship between weight and height gain, it appeared that weight and height faltering might have different aetiologies and as such probably require different interventions. However, it also has to be appreciated that reducing the burden of undernutrition in this community might have to span several generations, especially if the growth faltering described in the present study is familial.

Preventive interventions for undernutrition ought to target the determinants highlighted in the present study. Prevention of low birth weight, HIV, improved access to health care, and appropriate management of morbidity in infancy are likely, among others, to reduce the burden of malnutrition and its consequences. Reducing the strain posed by seasonality on food availability and morbidity patterns would reduce undernutrition in this population. This could be achieved through increased food production and food security, improved water and sanitation, education for both boys and girls, improved nutrition health education which is culturally acceptable and general improvements in the economic status of rural Malawian population.

Promotion of breast-feeding and proper supplementary feeding ought to be encouraged to improve the nutritional status of such communities. In

implementing short-term nutritional interventions the effect of season ought to be considered.

The present study also demonstrated that current supplementary feeding practices for moderately undernourished children using cereal / legume blends such as maize / soy flour (Likuni phala) may not be effective. New approaches are needed and in this regard RTUF offers such a possibility. In the present study it was easily acceptable and appeared to be a better option compared to maize / soy flour. While it is expensive in its present form, the main ingredients are readily available in Malawi such that a local affordable and sustainable formulation could be made. However, since the current formulation was intended for severely wasted children, newer formulations targeting stunted underweight children ought to be tested.

Another important aspect of the supplementation trial was the issue of supplement spill over to other than intended beneficiaries which none of the supplements overcame. This necessitates the need to include strong health education messages in supplementation programs to ensure the supplement reaches the intended targets. Because malnourished children tend to come from poor households, it might not be enough to target undernourished individuals but whole households. How this is done while maximising benefit and reducing costs is an issue that needs further investigation. This emphasizes the point that it is not enough to provide the right 'food' but also the to do so in the right context.

Overall, to combat undernutrition in this community a multisectoral ap-

proach is needed. Strategies such as UNICEF's selective approach to primary health care (GOBIFFF) and its variations ought to be encouraged. In this regard strategies such as integrated management of childhood illness ought to be encouraged. It has to be noted, however, that not all the suggested ap-

proaches are new. They are in place and implemented with variable success. What is important though is to discern why they do not seem to successfully alleviate the problem of undernutrition.

9. TARGETS FOR FUTURE RESEARCH

- The resolution of the issue of timing of growth faltering was to some extent hampered by the choice of an appropriate growth reference. However, it would be good to reanalyze the present data using the forthcoming WHO growth reference. This would help resolve the issues of timing of faltering and when to institute preventive interventions.
- In the present study, stunting was the major problem. However, the etiology of stunting is not very clear. Future research should attempt to explain the etiology as this will help in designing appropriate interventions. Several possible micronutrient deficiencies e.g. zinc have been suggested and this could be studied in the present population. Also the role of physical activity and social stimulation in linear growth faltering could be studied in this population.
- While growth faltering was a big problem, there were some children who grew quite well. Rather than addressing factors that separated those that became malnourished, it would also be good to analyse factors that determined those with above average growth in this population. This would highlight possible factors promoting growth in this population.
- RTUF was a promising alternative for supplementation of moderately undernourished children. However, our present results need to be validated in a larger study and in younger children. Furthermore a new formulation targeted at moderately undernourished children ought to be tested.
- Because our results and others suggest that cereal / legume supplementation for moderately undernourished children may not work as initially thought it is important to carry out controlled effectiveness trials to test whether it actually works.
- In the present study the problem of leakage and replacement of usual diet following dietary supplementation was highlighted. Qualitative studies to understand why this happens and how to reduce it are needed if supplementary feeding is going to be effective.

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11. REFERENCES

- ACC/SCN (2000): Fourth Report on the World Nutrition Situation ACC/SCN in collaboration with IFPRI, Geneva.
- ACC/SCN (2001a): What works? A review of the efficacy and effectiveness of nutrition interventions. Allen LH and Gillespie SR. ACC/SCN Geneva in collaboration with the Asian Development Bank, Manila.
- ACC/SCN (2001b): Nutrition and HIV/AIDS. Nutrition Policy Paper No. 20. ACC/SCN, Geneva.
- Ashworth A (1998): Effects of intrauterine growth retardation on mortality and morbidity in infants and young children. *Eur J Clin Nutr* 52(suppl 1):S34-S42.
- Bailey RC, Kamenga MC, Nsuami MJ, Nieberg P and St Louis MS (1999): Growth of children according to maternal and child HIV, immunological and disease characteristics: a prospective cohort study in Kinshasa, Democratic Republic of Congo. *Int J Epidemiol*. 28:532-540.
- Bakketeig Ls, Butte N, de Onis M, Kramer M, O'Donnell A, Prada JA and Hoffman HJ. (1998): Report of the IDECG working group on definitions, classifications, causes, mechanisms and prevention of IUGR. *Eur J Clin Nutr* 52(suppl 1):S94-S96.
- Barker DJP (1995): Fetal origins of coronary heart disease. *BMJ* 311: 171-174.
- Baqui AH and Black RE (2002): Childhood infectious diseases and their contribution to undernutrition. In: Public health issues in infant and child nutrition, pp 20-57. Black RE and Michaelsen KF Eds, Nestle Nutrition Workshop Series, Nestec Ltd, Vevey/Lippincott Williams & Wilkins, Philadelphia.
- Beaton GH and Ghassemi H (1982): Supplementary feeding programs for young children in developing countries. *Am J Clin Nutr* 35:864 – 916.
- Black RE and Michaelsen KF, Eds. (2002): Public health issues in infant and child nutrition. Nestle Nutrition Workshop Series, Nestec Ltd, Vevey/Lippincott Williams & Wilkins, Philadelphia.
- Branca FG, Pastore T, Demissie A and Ferro-Luzzi A (1993): The nutritional impact of seasonality in children and adults of rural Ethiopia. *Eur J Clin Nutr* 47:840 – 850.
- Briend A (1990): Is diarrhoea a major cause of malnutrition among under-five year old children in developing countries? *Eur J Clin Nutr* 44:611-628.
- Briend A, Hasan KHZ, Aziz KMA and Hoque BA (1989): Are diarrhoea control programmes likely to reduce childhood malnutrition? Observations from rural Bangladesh. *Lancet* 2:319-322.
- Briend A, Lacsala R, Prudhon C, Mounier B, Grellety Y, and Golden M H (1999): Ready to use therapeutic food for treatment of marasmus. *Lancet* 353:1767-8.
- Brown K H, Black R E, and Becker S (1982): Seasonal changes in nutritional status and the prevalence of malnutrition in a longitudinal study of young children in rural Bangladesh. *Am J Clin Nutr* 36:303 - 13.
- Brown KH, Dewey K and Allen L (1998): Complementary feeding of young children in developing countries: A review of current scientific knowledge. WHO/NUT/98.1. Geneva.
- Cole T J (1990): The LMS method for constructing normalised growth standards. *Eur J Clin Nutr* 1990; 44(suppl 1): 45-60.
- Cole T and Huigi P. (2002): LMS Program v.1.16. A program for calculating age-related reference centiles using the LMS method. Institute of Child Health. London.
- Collins S (2001): Changing the way we address severe malnutrition during famine. *Lancet* 358:498-501.
- Collins S and Sadler K (2002): Outpatient care for severely malnourished children in emergency relief programmes: a retrospective cohort study. *Lancet* 360:1824-1830.

- Costello AM de L (1989): Growth velocity and stunting in rural Nepal. *Arch. Dis. Child.* 64:1478-1482.
- Coutsoudis A, Pillay K, Spooner E, Kuhn L and Coovadia HM. (1999): Influence of infant feeding patterns on early mother to-child transmission of HIV -1 in Durban, South Africa: a prospective cohort study. *Lancet* 354:471-476.
- Coutsoudis A, Pillay K, Kuhn L, Spooner E, Tsai WY and Coovadia HM (2001): Method of feeding and transmission of HIV-1 from mothers to children by 15 months of age: prospective cohort study from Durban, South Africa. *AIDS* 15:379-387.
- Davis CE. (1976) The effect of regression to the mean in epidemiologic and clinical studies. *Am J Epidemiol* 104:493-496.
- De Onis M, Monteiro C, Akre J and Clugston G (1993): The worldwide magnitude of protein-energy malnutrition: an overview from the WHO Global Database on Child Growth. *Bull World Health Organ* 71:703-712.
- De Onis M, Garza C and Habicht JP (1997): Time for a new growth reference. *Pediatrics* 100(5): e8.
- De Onis M, Villar J and Gulmezoglu M (1998): Nutritional interventions to prevent intrauterine growth retardation; evidence from randomized controlled trials. *Eur J Clin Nutr.* 52(suppl 1):S83-S93.
- De Onis M, Frongillo EA and Blossner M (2000): Is malnutrition declining? An analysis of changes in levels of child malnutrition since 1980. *Bull World Health Organ* 78:1222-1233.
- Dewey KG (1998): Cross cultural patterns of growth and nutritional status of breast-fed infants. *Am J Clin Nutr* 67:10-7. 1998.
- Dewey KG (2002): Success of intervention programs to promote complementary feeding. In: *Public health issues in infant and child nutrition*, pp 199-216. Black RE and Michaelsen KF Eds, Nestle Nutrition Workshop Series, Nestec Ltd, Vevey/Lippincott Williams & Wilkins, Philadelphia.
- Dibley MJ, Goldsby JB, Staehling NW and Trowbridge FL (1987): Development of normalized curves for the international growth reference: Historical and technical considerations. *Am J Clin Nutr* 46:736-48.
- Dijkhuizen P (2001): Processed complementary foods in the World Food Programme. *Food Nutr Bull* 21: 62-64.
- Duggan MB, Alwar J and Milner RDG (1986): The nutritional cost of measles in Africa. *Arch Dis Child* 61:61-66.
- Espo M, Kulmala T, Maleta K, Cullinan T, Salin M-L and Ashorn P (2002): Determination of linear growth and predictors of severe stunting during infancy in rural Malawi. *Acta Paediatrica* 91: 1363-1370.
- Esrey SA, Feachem RG and Hughes JM (1985): Interventions for the control of diarrhoeal diseases among young children: improving water supplies and excreta disposal facilities. *Bull World Health Organ* 63:757-772.
- Eveleth PB and Tanner JM (1976): *Worldwide variation in Human growth*, pp.190. 2nd edn, Cambridge University Press, Cambridge.
- FAO (2000): *World food dietary assessment system*. World Food v 2.0. Accessed July 2002 <http://www.fao.org/infoods/software/worldfood.html>
- Ferguson E L, Gibson R S, Ounpuu S and Sabry J H (1989): The validity of the 24-hour recall for estimating the energy and selected nutrient intakes of a group of rural Malawian pre-school children. *Ecol Food Nutr.* 23: 273-285.
- Ferguson EL, Gadowsky SL, Huddle JM, Cullinan TR, Lehrfeld J and Gibson RS (1995): An interactive 24-h recall technique for assessing the adequacy of trace mineral intakes of rural Malawian women; its advantages and limitations. *Eur J Clin Nutr* 49: 565-578.
- Frongillo Jr EA, de Onis M and Hanson KMP (1997): Socio-economic and demographic factors are associated with worldwide patterns of stunting and wasting of children *J Nutr* 127:2302-2309.
- Garza C and de Onis M (1999): A new international growth reference for young children. *Am J Clin Nutr* 70(suppl.): S169-S172.
- Gelander L, Kalberg J and Albertsson-Wikland K (1994): Seasonality in lower leg length velocity in prepubertal children. *Acta Paediatr.* 83:1249-54.

- Gershoff SN, McGendy RB, Nondasuta A, and Tantiwongse P (1988): Nutritional studies in Thailand: effects of calories, nutrient supplements, and health interventions on growth of preschool Thai village children. *Am J Clin Nutr* 48(5):1214-1218.
- Golden MHN (1994): Is complete catch-up possible for stunted malnourished children? *Eur. J. Clin. Nutr.* 48(suppl. 1):S58-S71.
- Golden MHN (1995): Severe malnutrition. In *Oxford textbook of Medicine*, pp. 1278-1296. Eds. Weatherall DJ, Ledington JGG and Warell DA. 3rd ed vol 1, Oxford University Press, Oxford.
- Golding JSR (1994): The mechanical factors which influence bone growth. *Eur. J. Clin. Nutr.* 48(suppl. 1):S178-S185.
- Gomez F, Galvan RR, Frenk S, Cravioto M, Chavez R and Vasquez J (1956): Mortality in second and third degree malnutrition. *J Trop Paediatr* 2:77-83.
- Government of Malawi (1991): National programme of action for the survival, protection and development of children in the 1990's. UNICEF, Malawi.
- Grantham-McGregor S (1995): A review of studies of the effect of severe malnutrition on mental development. *J Nutr* 125(suppl):2233S-2238S.
- Habicht JP, Martorell R, Yarbrough C, Malina RM and Klein RE (1974): Height and weight standards of pre-school children. How relevant are ethnic differences in growth potential? *Lancet* 1:611-615.
- Hamill PV, Drizd TA, Johnson CL, Reed RB and Roche AF (1977). NCHS growth curves for children birth-18 years United States. *Vital Health Stat.* 11(165):1-74.
- Harper JM and Jansen GR (1985): Production of nutritious precooked foods in developing countries by low cost extrusion technology. *Food Reviews International.* 1:27-97.
- Hendratta L and Rohde JE (1988): Ten pitfalls of growth monitoring promotion. *Indian Journal of Paediatrics.* 55(suppl):S9-S15.
- Husaini MA, Karyadi L, Husaini YK, Sandjaja, Karyadi D, and Pollitt E (1991): Developmental effects of short-term supplementary feeding in nutritionally at-risk Indonesian infants. *Am J Clin Nutr* 54:799-804.
- Jalil F, Kalberg J, Hanson LA and Lindbland BS (1989): Growth disturbance in an urban area of Lahore, Pakistan related to feeding patterns, infections and age, sex, socio-economic factors and seasons. *Acta Paediatr.* 350(suppl):44-54.
- Janes MD, Macfarlane SBJ, and Moody JB (1981): Height and weight standards for Nigerian children *Ann Trop Paeds.* 1:27-37.
- Jason JM, Nieberg P and Marks JS (1984): Mortality and infectious disease associated with infant feeding practices in developing countries. *Paediatrics* 74(Suppl):702-727.
- Jelliffe EFP and Jelliffe DB (1987). Algorithms, growth monitoring and nutritional interventions. *J Trop Paediatr.* 33:290-295.
- Joseph KS (2002): Validating the fetal origins hypothesis: An epidemiologic challenge. In: *Public health issues in infant and child nutrition*, pp 199-216. Black RE and Michaelsen KF Eds, Nestle Nutrition Workshop Series, Nestec Ltd, Vevey/Lippincott Williams & Wilkins, Philadelphia.
- Kalberg J, Jalil F, Lam B, Low L, and Yeung CY (1994): Linear growth retardation in relation to the three phases of growth. *Eur J Clin Nutr* 48(suppl 1):S25-S44.
- Kuczmarski RJ, Ogden CL, Guo SS Grummer-Strawn LM, Flegal KM, Mei Z, Wei R, Cortin LR, Roche AF and Johnson CL (2002): 2000 CDC growth charts for the United States: methods and development. *National Center for Health statistics. Vital Health Stat.* 11(246):1-190.
- Kulmala T, Vaahtera M, Ndekha M, Cullinan T, Salin M-L and Ashorn P (2000a): The relationship between antenatal risk characteristics, place of delivery and adverse delivery outcome in rural Malawi. *Acta. Obs Gyn Scand* 79:984-990.
- Kulmala T, Vaahtera M, Ndekha MD, Koivisto A-M, Cullinan T, Salin M-L and Ashorn P (2000b): Inadequate socio-economic support for good health in rural Malawi. *East Afr Med J.* 77:168-171.
- Kulmala T, Vaahtera M, Ndekha MD, Koivisto A-M, Cullinan T, Salin M-L and Ashorn P (2001): Gestational health and predictors of

- newborn weight amongst pregnant women in rural Malawi. *Afr J Reprod Health* 5(3):99-108.
- Lartey A, Manu A, Brown KH, Pearson JM, and Dewey KG (1999): A randomised community based trial of the effects of improved, centrally processed complementary foods on growth and micronutrient status of Ghanaian infants from 6 to 12 mo of age. *Am J Clin Nutr* 70:391-404.
- Lutter CK, Mora JO, Habicht J-P, Rasmussen KM, Robson DS, and Guillermo Herrera M (1990): Age specific responsiveness of weight and length to nutritional supplementation. *Am J Clin Nutr* 51:359-64.
- Malawi government (1991): Ministry of finance, Department of Economic Planning and development. Report on a nutrition survey of high-income urban children in Malawi.
- Marshall WA (1971): Evaluation of growth rate in height over a period of less than one year. *Arch. Dis. Child.* 46:414-420.
- Martorell R, Habicht JP, Yarbrough C, Lechtig A, Klein E and Western KA (1975): Acute morbidity and physical growth in rural Guatemalan children. *Am J Dis Child* 129:1296-1301.
- Martorell R (1985): Child growth retardation: A discussion of its causes and of its relationship to health. In Blaxter KL, Waterlow JC eds. *Nutritional adaptation in man*, pp. 13-30. John Libbey, London.
- Martorell R, Kettle Khan L and Schroeder D (1994): Reversibility of stunting: epidemiological findings in children from developing countries. *Eur J Clin Nutr* 48(suppl 1):S45-S57.
- Martorell R (2001): Is wasting (thinness) a hidden problem in Latin America's children? *J Nutr* 131:1133-1134.
- Mata LJ ed. (1981): *The children of Santa Maria Caque. A prospective field study of health and growth.* MIT press, Massachusetts.
- McGregor IA, Rahman AK, Thompson B, Billewicz WZ and Thomson AM (1968): The growth of young children in a Gambian village. *Trans. R. Soc. Trop. Med. Hyg.* 62:341-352.
- Milner RDG (1988): Determinants of growth in utero. In Waterlow JC ed. *Linear growth in less developed countries*, pp. 91-108. Nestlé Nutrition Workshop Series, Vol 14. Nestle Ltd., Vevey /Raven Press, Ltd., New York.
- Mora JO, Herrera MG, Suescan J, de Navarro L and Wagner M (1981): The effects of nutritional supplementation on physical growth of children at risk of malnutrition. *Am J Clin Nutr* 34:1885-92.
- Morley D, Bricknell J, and Woodland M (1968): Factors influencing the growth and nutritional status of infants and young children in a Nigerian village. *Trans R Soc Trop Med Hyg* 62: 165-95.
- Morley D (1994): Malnutrition in children. In Lankinen KS, Bergström S, Mäkelä PH and Peltomaa M eds. *Health and disease in developing countries*, pp. 297-304. Macmillan Press, London and Basingstoke
- Nabarro D, Howard P, Cassels C, Pant M, Wijga A and Padfield N (1993): The importance of infections and environmental factors as possible determinants of growth retardation in children. In JC Waterlow ed. *Linear Growth Retardation in Less Developed Countries*, pp. 165-184. Raven Press, New York.
- National Statistical Office (Malawi) and OCR Macro (2001): *Malawi Demographic and Health Survey 2000.* National Statistical Office, Zomba, Malawi and OCR macro, Calverton, Maryland, USA.
- Ndekha M, Kulmala T, Vaahtera M, Cullinan T, Salin M and Ashorn P (2000): Seasonal variation in the dietary sources of energy for pregnant women in Lungwena, rural Malawi. *Ecol. Food and Nutr.* 38:605-622.
- Neumann CG and Harrison GG (1994): Onset and evolution of stunting in infants and children. Examples from the Human Nutrition Collaborative Research Support Program. Kenya and Egypt studies. *Eur J Clin Nutr* 48(suppl 1):S90-S102.
- Nykanen M, Tamaona W, Cullinan T, van Oosterze V and Ashorn P (1995): Verbal autopsy as a technique to establish causes of infant and child mortality. *East Afr Med J* 72:730-34.
- Pelletier DL, Low JW and Msukwa LAH (1991): Malawi maternal and child nutrition study: study design and anthropometric charac-

- teristics of children and adults. *Am J Hum Biol* 3, 347-361.
- Pelletier D, Frongillo EA, Schroeder D, and Habicht JP (1994): A methodology for estimating the contribution of malnutrition to child mortality in developing countries. *J Nutr* 124:2106S- 2122S.
- Pollit E and Arthur J (1989): Seasonality and weight gain during the first year of life. *Am. J. Hum. Biol.* 1:747-756.
- Pollit E and Oh S (1994): Early supplementary feeding, child development and health policy. *Food Nutr Bull* 15(3):208-214.
- Post CA and Victora CG (2001): The low prevalence of low weight-for-height deficits in Brazilian children is related to body proportions. *J Nutr* 131:1290-1296.
- Ramalingaswami V, Johnsson U and Rohde J (1996): The Asian Enigma. *Progress of Nations*. UNICEF. New York
- Reddy V, Bhashkaram P, Raghuramulu N, Milton RC, Rao V, Madhusudan J and Krishna KV (1986): Relationship between measles, malnutrition, and blindness: a prospective study in Indian children. *Am J Clin Nutr* 50:924-30.
- Rice AL, Hyder A, Caulfield L, Stoltzfus R, Fishman S, Frangakis C and Black RE (2002): Burden of disease caused by childhood under-nutrition. In: *Public health issues in infant and child nutrition*, pp 1-17. Black RE and Michaelsen KF Eds, Nestle Nutrition Workshop Series, Nestec Ltd, Vevey/Lippincott Williams & Wilkins, Philadelphia.
- Rivera J and Ruel MT (1997): Growth faltering starts in the first three months of life among rural Guatemalan children. *Eur J Clin Nutr* 51:92-96.
- Rowland MGM, Cole TJ and Whitehead RG (1977): A quantitative study into the role of infection in determining nutritional status in Gambian village children. *Br J Nutr* 37:441-450.
- SAS Institute Inc.1987. SAS-PC software, version 6.03. Cary, NC: SAS Institute.
- Schroeder DG, Martorell R, Rivera JA, Ruel MT, Habicht J-P (1995): Age differences in the impact of nutritional supplementation on growth. *J Nutr* 125(suppl):1051-9.
- Scrimshaw NS, Taylor CE and Gordon JE Eds (1968): *Interaction of nutrition and infection*. WHO monograph series no 57. Geneva: World health Organisation. Nutrition Policy Discussion Paper No 15.
- Shrimpton R, Victora CG, de Onis M, Lima RC, Blossner M and Clugston G (2001): Worldwide timing of growth faltering: Implications for nutritional interventions. *Paediatrics* 107(5):E75.
- Simondon KB, Gartner A, Berger J, Cornu A, Massamba JP, San Miguel JL, Ly C, Missotte I, Simondon F, Traisac P, Delpuech F, and Maire B (1996): Effect of early, short term supplementation on weight and linear growth of 4-7mo-old infants in developing countries: a four-country randomized trial. *Am J Clin Nutr* 64: 537-45.
- Smith L and Hadaad L (2000): Explaining child malnutrition in developing countries. A cross country analysis. IFPRI Research report III. IFPRI, Washington
- Stephensen CB (1999): Burden of infection on growth failure. *J Nutr* 129:S534-S538.
- Stubbs J, Ferres S, and Horgan G (2000): Energy density of foods: effects on energy intake. *Crit Rev Food Sci Nutr* 40(6):481-515.
- Taha TE, Dallabetta GA, Canner JK, Chiphangwi JD, Liomba NG, Hoover DR and Miotto PG (1995): The effect of human immunodeficiency virus infection on birth weight and infant and child mortality in urban Malawi, *Int J Epidemiol* 24(5):1022-9.
- Tomkins AM, Dunn DT, Hayes RJ and Bradley AK (1986): Seasonal variation in the nutritional status of urban Gambian children. *Br J Nutr* 56:333-343.
- Tomkins AM, Watson F (1989): Malnutrition and infection. A review. Advisory Committee on Co-ordination/Subcommittee on Nutrition, World Health Organisation, Geneva.
- UNICEF (1998): *The state of the world's children 1998*, Oxford University Press, Oxford.
- UNICEF (2002): *The state of the world's children 2002*, Oxford University Press, Oxford.
- Vaahtera M, Kulmala T, Ndekha M, Koivisto A-M, Cullinan T, Salin M-L and Ashorn P (2000a): Antenatal and perinatal predictors of

- infant mortality in rural Malawi. *Arch. Dis. Child.* 82:200-204.
- Vaahtera M, Kulmala T, Maleta K, Cullinan T, Salin M-L and Ashorn P (2000b): Epidemiology and predictors of infant morbidity in rural Malawi. *Paediatr. Perinat. Epidemiol.* 14:363-371.
- Vaahtera M, Kulmala T, Hietanen A, Ndekha M, Cullinan T, Salin M-L and Ashorn P (2001): Breastfeeding and complementary feeding practices in rural Malawi. *Acta Paediatrica* 3:328-332.
- Victora CG (1991): The association between wasting and stunting: An international perspective. *J Nutr* 122:1105-1110.
- Victora CG, Morris SS, Barros FC, de Onis M and Yip R (1998): The NCHS reference and the growth of breast and bottle-fed infants. *J Nutr* 128:1134-1138.
- Walker SP and Golden MHN (1988): Growth in length of children recovering from severe malnutrition. *Eur J Clin Nutr* 42:395-404.
- Waterlow JC (1976): Classification and definition of protein energy malnutrition. WHO Monograph Series no 68. World Health Organisation, Geneva.
- Waterlow JC (1992): Protein energy malnutrition. Edward Arnold, London
- Waterlow JC (1994): Relationship of gain in height to gain in weight. *Eur J Clin Nutr* 48(suppl):S72-S74.
- Waterlow JC and Schurch B Eds. (1994): Causes and mechanisms of linear growth retardation. Proceedings of an IDECG workshop. *Eur J Clin Nutr* 48(suppl 1).
- Waterlow JC, Buzina R, Keller W, Lane JM, Nichman MZ And Tanner JM (1977): The presentation and use of height and weight data for comparing the nutritional status of groups of children under the age of 10 years. *Bull World Health Organ* 55:489- 498.
- Wellcome Trust Working Party (1970): Classification of infantile malnutrition *Lancet* 2:302-303.
- West, CE, Pepping F and Temalilwa CR (1988): The Composition of Foods Commonly Eaten in East Africa. Wageningen Agricultural University, Wageningen, Netherland.
- Whitehead RG and Paul AA (1984): Growth charts and the assessment of infant feeding practices in the western world and in developing countries. *Early Hum Dev.* 3:187-207.
- WHO (1983): Measuring Change in Nutritional Status: Guidelines for Assessing Nutritional impact of Supplementary Feeding Programmes for Vulnerable Groups. World Health Organisation, Geneva.
- WHO (1999): Management of severe malnutrition: a manual for physicians and other senior health workers. World health Organisation, Geneva.
- Xu X, Wang WP, Guo ZP, Cheung YB and Kalberg J (2001): Seasonality of growth in Shanghai infants (n=4128) born in 11 consecutive years. *Eur J Clin Nutr* 55:714-725.
- Yao M and Roberts SB (2001): Dietary energy density and weight regulation. *Nutr Rev* 59(8):247-58.

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