Protein-Energy Malnutrition (PEM) and Undernutrition
Causes, Consequences, Interactions and Global Trends

Keith P. West, Jr., Dr.P.H.
International Nutrition
“PEM”: Invariably reflects combined deficiencies in...

- **Protein**: deficit in amino acids needed for cell structure, function
- **Energy**: calories (or joules) derived from macronutrients: protein, carbohydrate and fat
- **Micronutrients**: vitamin A, B-complex, iron, zinc, calcium, others
Undernutrition through Life Stages

Child and Maternal Health Problems

• Infant or Child
• Infection (diarrhea, ARI)
• Poor growth
• Impaired mental, motor and behavioral development
• Death

• Mother
• Obstetric morbidity
• Infection/sepsis
• Anemia
• Death

Nutritional Deficiencies

• PEM
• Micronutrient Defic: Vitamin A, zinc, iron, iodine, folate, others

• Behavioral Causes: Related to breast feeding, complementary feeding, HH diet, low SES, poor education
IUGR: Due to Maternal Malnourishment, Disease, Noxious Exposures...

N=4615 Newborns in NW Bangladesh
Mean= 2442 grams

Low birth weight

Photo: K West
Postnatal nutrition also can dramatically affect early child growth.

From mild growth deficit detectable by anthropometry or biochemical indices to severe wasting malnutrition (e.g., Marasmus).

Shown: 1-year-old twins in Chittagong, Bangladesh.
Left: Male
Right: Female

Photo: K West
Severe Childhood PEM

- **Kwashiorkor**: disease when child is displaced from breast (Cicely Williams, 1935, Gold Coast, W Africa)
- **Marasmus**: Extreme wasting
- **Marasmic-Kwashiorkor**

Kwashiorkor ↔ Marasmus

Different manifestations of similar nutritional deficits of energy, protein, micronutrients; unique causal roles for aflatoxins & oxidative stress in Kwashiorkor?
• **Marasmus**
  • Severely wasted (emaciated) & stunted
  • Very low WAZ
  • “Balanced” starvation
  • “Old Man” face, wrinkled appearance, sparse hair
  • No edema, fatty liver, skin changes
  • Too little breast milk or complementary foods
  • < 2 yrs of age

Photo: K West
Too little breast milk, often after 6 mo of age

Dilute and unhygienic formula or bottle feeding

Photo: K West
- Kwashiorkor
- Edema
- Mental changes
- Hair changes
- Fatty liver
- Dermatosis (skin lesions)
- Infection
- Mod low WAZ, wasting
- High case fatality
- Low prevalence
- 1st to 3rd yrs of life

Photo: K West
Three-year old Indonesian boy with measles, marasmic-kwashiorkor and keratomalacia (right eye).

The synergy between undernutrition and infection can be devastating, threatening a child's sight and life.

Photo: Alfred Sommer
Causes of Severe Childhood PEM

• Chronic, severely low energy and protein intake
  • Exclusive breast feeding for too long
  • Dilution of formula
  • Unclean/non-nutritious, complementary foods of low energy and micronutrient density
• Infection (eg, measles, diarrhea, others)
• Xenobiotics (aflatoxins)
Treatment of Severe PEM

- Nutritious feeds:
  - Breast milk;
  - Liquid feeds of skimmed milk, oil, sugar; soft
  - Cereal gruels with milk, oil, sugar soft
  - Soft ripe fruit, cooked vegetables

- Establish a daily, graduated intake of -
  - ~3-4 g protein per kg (actual) body wt
  - ~200 kcal of energy per kg body wt

Treatment of Severe PEM (2)

- More frequent small feeds better than large meals
- Micronutrient supplements:
  - To treat clinical conditions (eg, anemia, xerophthalmia)
  - To prevent further deficiencies
- Water for thirst
- Treat infections and illnesses; eg,
  - Diarrhea: ORS & zinc
  - Antibiotics, as indicated
- Prevent hypothermia
### 1-year After Treatment of Severe Malnutrition, Bangladesh
(Khanum et al, Am J Clin Nutr 1998;67:940-5)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diarrhea</td>
<td>67%</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>58%</td>
</tr>
<tr>
<td>Mortality</td>
<td>2.3%</td>
</tr>
<tr>
<td>Mean WHZ</td>
<td>adequate</td>
</tr>
<tr>
<td>Mean HAZ</td>
<td>very low</td>
</tr>
</tbody>
</table>

Returning to same high-risk home setting
### Mortality One Year Following Treatment for Severe Wasting Malnutrition

<table>
<thead>
<tr>
<th>Country</th>
<th>Mortality Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanzania</td>
<td>8%</td>
</tr>
<tr>
<td>Tanzania</td>
<td>41%</td>
</tr>
<tr>
<td>Zaire</td>
<td>19%</td>
</tr>
<tr>
<td>Niger</td>
<td>18%</td>
</tr>
<tr>
<td>Philippines</td>
<td>12%</td>
</tr>
<tr>
<td>Nigeria</td>
<td>15%</td>
</tr>
<tr>
<td>South Africa</td>
<td>38%</td>
</tr>
</tbody>
</table>
Children can remain wasted and underweight throughout preschool years.
Undernutrition can be milder, "hidden", reflecting chronic low intake of calories, protein & micronutrients, affecting survival & quality of life

Photo: K West
Anthropometric Measurements of Nutritional Status

- Weight
- Length/height
- Mid upper arm circumference (MUAC)
- Chest circumference
- Head circumference
- Skinfold measurements: Tricipital and Subscapular
NCHS growth curves depicting percentiles of stature and weight for age of American girls, 2 to 18 years of age.

National Center for Health Statistics

For more information see: Hamill et al AJCN 1979;32:607
NCHS growth curves depicting percentiles of length and weight for age of American girls, birth to 36 months.

National Center for Health Statistics

For more information see: Hamill et al AJCN 1979;32:607
Anthropometric classification of PEM

• **Underweight**: Weight for age < -2SD of the *median* age-sex specific weight of the NCHS/WHO reference

• **Stunting**: Height for age < -2SD of the median age-sex specific height of the NCHS/WHO reference

• **Wasting**: Weight for height < -2SD of the median weight at a given height of the NCHS/WHO reference
### Anthropometric Cutoffs for Assessing Undernutrition in

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Basis</th>
<th>Moderate or Severe</th>
<th>Moderate or worse</th>
<th>Mild or worse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt for Age</td>
<td>% med SND</td>
<td>&lt;60% &lt; -3 Z</td>
<td>&lt;75% &lt; -2 Z</td>
<td>&lt;90% &lt; -1 Z</td>
</tr>
<tr>
<td>Ht for Age</td>
<td>% med SND</td>
<td>&lt;85% &lt; -3 Z</td>
<td>&lt;90% &lt; -2 Z</td>
<td>&lt;95% &lt; -1 Z</td>
</tr>
<tr>
<td>Wt for Ht</td>
<td>% med SND</td>
<td>&lt;70% &lt; -3 Z</td>
<td>&lt;80% &lt; -2 Z</td>
<td>&lt;90% &lt; -1 Z</td>
</tr>
<tr>
<td>MUAC (cm)</td>
<td>Absolute (1-5 yrs)</td>
<td>&lt;11.5</td>
<td>&lt;12.5</td>
<td>&lt;13.5</td>
</tr>
<tr>
<td>Ht-for-Age</td>
<td>Normal (&gt; - 2 SD HAZ)</td>
<td>Stunted (&lt; - 2 SD HAZ)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------------</td>
<td>------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wt-for-Ht</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal (&gt; - 2 SD WHZ)</td>
<td>Normal</td>
<td>Stunted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wasted (&lt; - 2 SD WHZ)</td>
<td>Wasted</td>
<td>Stunted &amp; Wasted</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

JC Waterlow BWHO 1977;55:489
## Classification of Nutritional Status of Children by Anthropometry

(Waterlow Classification)

<table>
<thead>
<tr>
<th>Ht-for-Age</th>
<th>Wt-for-Ht</th>
<th>Normal (&gt; - 2 SD HAZ)</th>
<th>Stunted (&lt; - 2 SD HAZ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal (&gt; - 2 SD WHZ)</td>
<td>Normal</td>
<td></td>
<td>Stunted</td>
</tr>
<tr>
<td>Wasted (&lt; - 2 SD WHZ)</td>
<td>Wasted</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Underweight**

(Low wt for age)

JC Waterlow BWHO 1977;55:489
## Alternative Classification of Wasting Status of Children

<table>
<thead>
<tr>
<th>MUAC (cm)</th>
<th>Ht-for-Age Normal (＞ - 2 SD HZ)</th>
<th>Stunted (＜ - 2 SD WHZ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Normal</td>
<td>Stunted</td>
</tr>
<tr>
<td>(＞ 12.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wasted</td>
<td>Wasted</td>
<td>Stunted &amp; Wasted</td>
</tr>
<tr>
<td>(＜ 12.5)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MUAC = mid-upper arm circumference
Means Weight for Age by Region

Age (months)

Z-score (NCHS)

Africa

Asia

Latin America and Caribbean

Source: DHS/IFPRI
Prevalence and Numbers of Underweight Children by Region, 1990

ACC/SCN Report, 1992
Darker the color, greater the hunger & undernutrition
FAO Estimation of Undernourishment

- Attempts to capture number & % of in each country” whose food access is deemed to be inadequate”; reflecting joint roles of food supplies & household incomes in affecting food security.

- Calculated from 3 statistics:
  - Daily per capita dietary energy supply
  - CV (spread) in energy intake within a country, based on representative HH food intake surveys
  - Minimum daily per capita energy requirement , based on age-sex body weight and activity level weighted by age-sex population fractions for “typical” person

LC Smith, IFPRI, May 1998
The South-Asian Enigma

- Why are rates of malnutrition higher in South Asia than Sub-Saharan Africa?
  - Poverty
  - Agricultural performance is not the issue
  - Vegetarian diet
  - Government neglect
  - Higher mortality rates in SS Africa
- Women’s status (gender discrimination)
- Poor child feeding and care practices
- Low birth weight (reflecting poor maternal status e.g. weight gain and anemia)
Figure II-1: A typical pattern of prevalence rates of wasted and stunted children in a developing country

Note: The figure was created on basis of a review of Demographic Health Survey data of many different countries.
As the percent of children who are malnourished increases in a population, so too does the proportion of child deaths attributable to undernutrition.

\[ \text{PAR} = 0.87 + 1.42X - 0.0075X^2 \]

BASICS Project
USAID
Undernutrition is chronic in many parts of the world, affecting one generation after another, throughout the "Life Cycle". The longer-term consequences of mild-to-moderate undernutrition in early life are only beginning to be understood (eg, the early origins hypothesis of chronic disease risk; )

Photo: Keith West
UNICEF conceptual model of causation of CHRONIC undernutrition

UNICEF Conceptual Model of the Causation of Undernutrition, Modified To Include Its Consequences
Health Consequences of Undernutrition and PEM
The “Vicious Cycle” of Undernutrition and Infection

- Undernutrition
  - Phagocytic & bactericidal activities reduced
  - Malabsorption of nutrients
  - Metabolic losses
- Infection
  - Loss of appetite
  - Reduced food intake
- Complement system impaired and decreased lysozyme levels in leucocytes
- Secretory IgA levels are low and antibody responses reduced
- Reduced cell-mediated immune response
Major Causes of Death among Children

- Diarrhoea: 12%
- Other: 29%
- Perinatal: 22%
- HIV/AIDS: 4%
- Pneumonia: 20%
- Malaria: 8%
- Measles: 5%
- Deaths associated with undernutrition: 60%

For more information see: EIP/WHO.Caulfield LE, Black RE. Year 2000
Malnutrition and Incidence and Duration of Diarrhea in African Children (Tomkkins A Lancet 1981)

<table>
<thead>
<tr>
<th>Nutritional status</th>
<th>n</th>
<th>Attack rate per child in 3 mo</th>
<th>% Time with Diarrhea</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wt/age</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;75%</td>
<td>220</td>
<td>1.2</td>
<td>8.5</td>
</tr>
<tr>
<td>&lt;75%</td>
<td>123</td>
<td>1.5</td>
<td>11.3*</td>
</tr>
<tr>
<td><strong>Ht/age</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;90%</td>
<td>245</td>
<td>1.4</td>
<td>7.9</td>
</tr>
<tr>
<td>&lt;90%</td>
<td>98</td>
<td>1.4</td>
<td>10.8*</td>
</tr>
<tr>
<td><strong>Wt/Ht</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;80%</td>
<td>302</td>
<td>1.3</td>
<td>7.6</td>
</tr>
<tr>
<td>&lt;80%</td>
<td>41</td>
<td>1.9*</td>
<td>13.6*</td>
</tr>
</tbody>
</table>
## Malnutrition and Diarrheal Morbidity in Children < 24 mo in Bangladesh

*(Black et al AJCN 1984)*

<table>
<thead>
<tr>
<th>Nutritional status</th>
<th>Duration (mean days)</th>
<th>Incidence (episodes/child)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt/length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥90%</td>
<td>6.8</td>
<td>16.9</td>
</tr>
<tr>
<td>80-89%</td>
<td>8.5</td>
<td>16.2</td>
</tr>
<tr>
<td>&lt;80%</td>
<td>10.6*</td>
<td>16.4</td>
</tr>
</tbody>
</table>

*p<0.05
<table>
<thead>
<tr>
<th>Country</th>
<th>Age</th>
<th>Diarrhea</th>
<th>Fever</th>
<th>Apathy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uganda</td>
<td>6-36</td>
<td>-5.4</td>
<td>-4.0</td>
<td>-</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>6-48</td>
<td>-5.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>6-32</td>
<td>-4.4</td>
<td>-10.3</td>
<td>-</td>
</tr>
<tr>
<td>Jamaica</td>
<td>9-48</td>
<td>-8.4</td>
<td>-16.8</td>
<td>-15.0</td>
</tr>
</tbody>
</table>
## Effect of Morbidity on Weight Change
(Walker AJCN 1992)

<table>
<thead>
<tr>
<th>Country</th>
<th>Age</th>
<th>Diarrhea</th>
<th>Fever</th>
<th>Apathy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guatemala</td>
<td>12-36</td>
<td>-3.5</td>
<td>-</td>
<td>-2.3</td>
</tr>
<tr>
<td>Gambia</td>
<td>Rural</td>
<td>6-36</td>
<td>-25.8</td>
<td>-20.0</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>0-24</td>
<td>-3.7</td>
<td>-</td>
</tr>
<tr>
<td>Sudan</td>
<td>3-12</td>
<td>-32.1</td>
<td>-29.5</td>
<td>-</td>
</tr>
</tbody>
</table>
### Relative Risk of Preschool Child Death by Weight for Age

<table>
<thead>
<tr>
<th>Cause</th>
<th>&lt;-3 Z</th>
<th>-2 to -3 Z</th>
<th>-1 to -2 Z</th>
<th>&gt; -1 Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diarrhea</td>
<td>12.5</td>
<td>5.4</td>
<td>2.3</td>
<td>1.0</td>
</tr>
<tr>
<td>ALRI</td>
<td>8.1</td>
<td>4.0</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Malaria</td>
<td>9.5</td>
<td>4.5</td>
<td>2.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Measles</td>
<td>5.2</td>
<td>3.0</td>
<td>1.7</td>
<td>1.0</td>
</tr>
<tr>
<td>All causes</td>
<td>8.7</td>
<td>4.2</td>
<td>2.1</td>
<td>1.0</td>
</tr>
</tbody>
</table>

S Fishman et al, CQHR, Vol1, WHO 2004
### Mortality of Tanzanian Children 6-60 Mo of Age within ~ 2 Years after Hospitalization for Pneumonia

<table>
<thead>
<tr>
<th>Status Indicator</th>
<th>Adj HR for Mortality</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ht for Age &lt; -2 Z (Stunted)</td>
<td>2.0</td>
<td>1.2-3.3</td>
</tr>
<tr>
<td>Wt for Ht &lt; -2 Z (Wasted)</td>
<td>2.9</td>
<td>1.8-4.6</td>
</tr>
<tr>
<td>Wt for Age &lt; -2 Z (Underweight)</td>
<td>1.6</td>
<td>0.8-3.0</td>
</tr>
<tr>
<td>MUAC &lt;25 %ile</td>
<td>1.9</td>
<td>1.1-3.1</td>
</tr>
</tbody>
</table>

Villamor et al Int J Epidemiol 2005;34:61-68
HIV Infection and Mortality by Level of Wasting Status in Tanzanian Children 6-60 Mo of Age

<table>
<thead>
<tr>
<th>Wasting (&lt;-2 WHZ)</th>
<th>HR for Mortality HIV+/HIV-</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>1.6</td>
<td>0.5-4.6</td>
</tr>
<tr>
<td>Yes</td>
<td>5.2</td>
<td>2.5-10.6</td>
</tr>
</tbody>
</table>

Adjusted for age, ht for age, Hb concentration, severity of pneumonia at baseline, water supply, vitamin A receipt

Villamor et al Int J Epidemiol 2005;34:61-68
Conceptual Model of the Effects of Undernutrition throughout the Life Cycle
