Water, Sanitation, and the Prevention of Stunting: An Holistic View of Why Food Isn’t Enough

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What is stunting, and why focus it?

• A stunted child is short for age (low “height for age”). A child that is $\leq 2$ SD below his/her mean height for age (“HAZ $\leq -2$”) is stunted.

• Stunting is linked to: diminished scholastic achievement and intellectual function, reduced lifetime earnings, short adult stature, (and in women) adverse pregnancy outcomes.

• UNICEF 2013: 165 million children stunted... India: 48% of children. Yemen: almost 60%
• Stunting reflects under-nutrition *in utero* and during infancy / early childhood - critical periods of physical and cognitive growth.

-Small Brain Volume (atrophy)
-Lower IQ when stunted children compared to non-stunted children

Same age girls in Bangladesh (UNICEF)
Window of Opportunity to end stunting: Pregnancy, and first 24 months of age

Mean height for age z scores by age, relative to the WHO standard, according to region (1–59 months). Victora C G et al. Pediatrics 2010;125:e473-e480
Nutrition Interventions (listed below) only address a minor portion of stunting

PREGNANCY

EARLY CHILDHOOD

ADOLESCENT, PRECONCEPTION, GESTATIONAL, AND MATERNAL NUTRITION
Adequate Calories (proteins, fats, carbs) in all life stages
Diversity of micronutrients, vitamins, high quality proteins
Optimal breastfeeding, responsive feeding practices, stimulation
Good complementary feeding 6-23 months, dietary diversity
Wealth, education – [be sure to choose your parents well]
Others.....
Adequate and nutritious foods are necessary but not sufficient.

**Mycotoxins**: Fungal food toxins which impair growth and immunity

**Environmental Enteropathy**: Inflamed, leaky, dysfunctional intestines

The gut **Microbiome** - gut bacteria gone bad
First, a focus on diarrheal disease

As an infant is weaned, s/he is exposed to food and water which is contaminated. Children who crawl around on the floor eat and sample dirt, chicken poop, whatever. **Diarrhea**, other illnesses → **malnutrition**
Interventions for the control of diarrhoeal diseases among young children: improving water supplies and excreta disposal facilities

S. A. Esrey,¹ R. G. Feachem,² & J. M. Hughes³

A theoretical model is proposed that relates the level of ingestion of diarrhoea-causing pathogens to the frequency of diarrhoea in the community. The implications of this model are that, in poor communities with inadequate water supply and excreta disposal, reducing the level of enteric pathogen ingestion by a given amount will have a greater impact on diarrhoea mortality rates than on morbidity rates, a greater impact on the incidence rate of severe diarrhoea than on that of mild diarrhoea, and a greater impact on diarrhoea caused by pathogens having high infectious doses than on diarrhoea caused by pathogens of a low infectious dose. The impact of water supply and sanitation on diarrhoea, related infections, nutritional status, and mortality is analysed by reviewing 67 studies from 28 countries. The median reductions in diarrhoea morbidity rates are 22% from all studies and 27% from a few better-designed studies. All studies of the impact on total mortality rates show a median reduction of 21%, while the few better-designed studies give a median reduction of 30%. Improvements in water quality have less of an impact than improvements in water availability or excreta disposal.

Bull WHO 1985
Impact on nutritional anthropometry. If water supply and excreta disposal improvements reduce diarrhoea incidence rates or duration among young children, then nutritional anthropometric indicators should also improve because of the inverse relationship between time spent with diarrhoea and child growth (58, 68). Six studies that investigated the relationship between water supply or excreta disposal improvements and nutritional status are summarized in Table 5. All six studies reported an association between improved water supply or excreta disposal and improved nutritional status. In two studies, in Fiji and the Philippines, attempts to control for extraneous risk factors reduced the differences between the control and intervention groups, but some of these differences were nonetheless found to be statistically significant.
2005 Update: Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis


<table>
<thead>
<tr>
<th>Category</th>
<th>Number of studies</th>
<th>Relative risk (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hygiene</td>
<td>11</td>
<td>0.63 (0.52–0.77)</td>
</tr>
<tr>
<td>Excluding poor quality studies</td>
<td>8</td>
<td>0.55 (0.40–0.75)</td>
</tr>
<tr>
<td>Handwashing</td>
<td>5</td>
<td>0.56 (0.33–0.93)</td>
</tr>
<tr>
<td>Education</td>
<td>6</td>
<td>0.72 (0.63–0.83)</td>
</tr>
<tr>
<td>Sanitation</td>
<td>2</td>
<td>0.68 (0.53–0.87)</td>
</tr>
<tr>
<td>Water supply</td>
<td>6</td>
<td>0.75 (0.62–0.91)</td>
</tr>
<tr>
<td>Diarrhoea only</td>
<td>4</td>
<td>1.03 (0.73–1.46)</td>
</tr>
<tr>
<td>Household connection</td>
<td>2</td>
<td>0.90 (0.43–1.93)</td>
</tr>
<tr>
<td>Standpipe or community connection</td>
<td>3</td>
<td>0.94 (0.65–1.35)</td>
</tr>
<tr>
<td>Water quality</td>
<td>15</td>
<td>0.69 (0.53–0.89)</td>
</tr>
<tr>
<td>Source treatment only</td>
<td>3</td>
<td>0.89 (0.42–1.90)</td>
</tr>
<tr>
<td>Household treatment only</td>
<td>12</td>
<td>0.65 (0.48–0.88)</td>
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<tr>
<td>Household treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• excluding poor quality studies</td>
<td>8</td>
<td>0.61 (0.46–0.81)</td>
</tr>
<tr>
<td>• rural location</td>
<td>6</td>
<td>0.61 (0.39–0.94)</td>
</tr>
<tr>
<td>• urban/periurban locations</td>
<td>5</td>
<td>0.86 (0.57–1.28)</td>
</tr>
<tr>
<td>• urban/periurban excluding Satha35</td>
<td>4</td>
<td>0.74 (0.65–0.85)</td>
</tr>
<tr>
<td>Multiple</td>
<td>5</td>
<td>0.67 (0.59–0.76)</td>
</tr>
</tbody>
</table>
Child has Diarrhea:
1. Treat Child To Prevent Death, Morbidity
2. To Prevent Diarrhea: Add Water and Sanitation
... focus moves to enteropathy

- 1970s: “tropical enteropathy” was identified in South and Southeast Asia, Africa
- Characterized by blunted intestinal villi, ↑ intestinal permeability; fat and carbohydrate malabsorption, and increased protein needs.
- Found in both children and adults
- Realization it was epidemiologically linked to living in an unsanitary environment
ENVIRONMENTAL ENTEROPATHY (EE)

- People living in contaminated environments have leaky, chronically inflamed intestines
- Gut: short blunted villi, tissue infiltrated with inflammatory cells. Good evidence that gut contents, endotoxins ‘leak’ across the intestine.
- Associated with ↑ caloric, protein, carbohydrate needs
Mild (left) and severe (right) villus blunting
Less absorptive surface area is present
### Table 4

Intestinal infections detected in 3,260 monthly samples from asymptomatic participants*

<table>
<thead>
<tr>
<th>Organism</th>
<th>Frequency of isolation</th>
<th>Frequency of isolation one month before investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptosporidium parvum</td>
<td>31</td>
<td>1</td>
</tr>
<tr>
<td>Isospora belli</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Microsporidia</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Giardia intestinalis</td>
<td>40</td>
<td>5</td>
</tr>
<tr>
<td>Blastocystis hominis</td>
<td>236</td>
<td>19</td>
</tr>
<tr>
<td>Ascaris lumbricoides</td>
<td>489</td>
<td>33</td>
</tr>
<tr>
<td>Hookworm</td>
<td>92</td>
<td>13</td>
</tr>
<tr>
<td>Strongyloides stercoralis</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Schistosoma mansoni</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Trichuris trichiura</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Taenia saginata</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Iodamoeba butschlii</td>
<td>120</td>
<td>5</td>
</tr>
<tr>
<td>Entamoeba histolytica/dispar</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Entamoeba hartmannii</td>
<td>47</td>
<td>4</td>
</tr>
<tr>
<td>Chilomastix mesnili</td>
<td>208</td>
<td>25</td>
</tr>
<tr>
<td>Endolimax nana</td>
<td>259</td>
<td>12</td>
</tr>
<tr>
<td>Hymenolepis nana</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>Salmonella spp.</td>
<td>44</td>
<td>4</td>
</tr>
<tr>
<td>Shigella spp.</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Aeromonas hydrophila</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>Citrobacter rodentium</td>
<td>608</td>
<td>42</td>
</tr>
<tr>
<td>Vibrio cholerae</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

*The table shows which organisms were isolated from asymptomatic participants and which organisms were isolated from participants in the month prior to investigations carried.
• Classic water, sanitation, hygiene (WASH) interventions reduce pathogen transmission;
• Tropical enteropathy \(\rightarrow\) environmental enteropathy (EE) when the linkage to unsanitary environment recognized. Hallmark of EE is gut mucosal damage, permeability.
• Recognition that persons with EE have “asymptomatic” infections with pathogens.
• Next question: how much of stunting can be explained by environmental enteropathy?

- Infants aged 2-10 months recruited into longitudinal study (n=119 with at least 3 observations). Infants had diarrhea 7.5% of the time and “growth depressing permeability” 76% of the time. **43% of stunting** explained by increased gut permeability and decreased absorptive capacity (differential absorption of lactulose and mannitol) e.g. by E.E.

Fig 2—The relation between intestinal permeability (expressed as loge lactulose:mannitol ratio) and mean monthly (a) length and (b) weight growth of 119 rural Gambian infants.

Significance of regression coefficients, p<0.001.
Intestinal permeability and mucosal damage (left) and antibody to bacterial endotoxin (right) rise after weaning when exposure to pathogens increases and nutritional faltering accelerates.

Lunn et al Lancet 1991
REALITY: All children at risk of Environmental Enteropathy, linked to Unsanitary Environment & Asymptomatic Infection with Pathogens
Handwashing is “necessary but not sufficient”

**Original Research Article**

Hand-Washing, Subclinical Infections, and Growth: A Longitudinal Evaluation of an Intervention in Nepali Slums

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2 Department of Biological Anthropology, University of Cambridge, Cambridge, CB2 3DZ, United Kingdom
3 Jackson Institute for Global Affairs and Department of Anthropology, Yale University, New Haven, Connecticut

- 1st longitudinal study to assess hand-washing and enteropathy. 45 intervention, 43 control
- ↑enteropathy = ↓ growth (p<0.01 HAZ, WAZ)
- Handwashing led to 41% ↓ diarrhea morbidity
- **No change in markers of enteropathy**
- *HW alone* doesn’t address chronic subclinical infxn
Going from > 80% without sanitation (far right) to 0% without sanitation moves the HAZ score from under -2 to just under -1. Thus data collected from 60 counties, over time, indicates a clean environment does lead to decreased stunting.

Figure 1: Open defecation predicts child height, across DHS survey round country-years
Solid OLS regression lines weight by country population; dashed lines are unweighted.
Key findings Spear’s analysis of 140 DHS from 65 ‘developing’ countries

• Open defecation (a certain marker of a fecally “contaminated environment”) is linked to a **1.24 S.D. decrease** in the height of children.

• **This alone** accounts for **54%** of the between-country height variation (next slide).

• Open defecation and a lack of sanitation in an household, along with country GDP, predict child height **more than** mother’s height or education; governance; or infrastructure.
Enteropathy & Nutrition

- Environmental enteropathy: malabsorption, permeable and chronically inflamed gut; infection with pathogens due to unsanitary environment (“bad microbiome”) AND
- Increased metabolic needs because of chronic intestinal inflammation and less absorption (↑ need for calories, carbos, fats, proteins...)
- Onset: weaning – when contaminated food and water lead to increased infections
EE goes away when a contaminated environment is removed. US Peace Corps volunteers develop EE when they live in rural African villages. When they return to the US, their EE goes away. The absence of fecal material – be it human or animal – in the environment both prevents and “treats” EE. Water/sanitation is critical to this separation.

- Dean Spears has looked at open defecation as a marker of sanitation using 140 DHS data sets from 60 countries.

**How much stunting is due to poor sanitation?**
Water is used for multiple purposes

• Agriculture / Irrigation
• Food, Cooking
• Industrial uses
• Support farm animals
• Recreation
• Worship
• Aquaculture and Fisheries
High potential for animals and people to contaminate household environment and water with feces
### AGRICULTURAL WASTEWATER

<table>
<thead>
<tr>
<th>ORGANISM</th>
<th>TYPICAL SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROTAVIRUS</td>
<td>HUMANS; PERHAPS ZOONOTIC</td>
</tr>
<tr>
<td>HEPATITIS A</td>
<td>HUMANS</td>
</tr>
<tr>
<td>HEPATITIS E</td>
<td>HUMANS, SWINE</td>
</tr>
<tr>
<td><em>E. coli</em> (bacteria)</td>
<td>CATTLE, HUMANS</td>
</tr>
<tr>
<td><em>Shigella</em> species</td>
<td>HUMANS</td>
</tr>
<tr>
<td><em>Salmonella enterica</em> (bacteria)</td>
<td>CATTLE, POULTRY, SWINE, HUMANS</td>
</tr>
<tr>
<td><em>Campylobacter jejuni</em> (bacteria)</td>
<td>POULTRY</td>
</tr>
<tr>
<td><em>Cryptosporidium</em> (protozoan)</td>
<td>CATTLE, HUMANS, OTHER FARM ANIMALS</td>
</tr>
<tr>
<td><em>Microsporidia</em> (fungus)</td>
<td>FARM AND DOMESTIC ANIMALS, HUMANS</td>
</tr>
</tbody>
</table>

* Causes chronic diarrhea, wasting, malnutrition in people with HIV/AIDS

*Cryptosporidium* – a leading cause of diarrhea children < 24 months; known to cause stunting; and African children have x 4 risk of death in next year

Pathogens in Rural and Agricultural Water and Watersheds. USDA 2010
Solutions

• Classic water and sanitation for household – water supply NOT same for animals unless treated; hand-washing; human feces kept out of wastewater

• Agricultural hygiene – barriers to keep feces and crud out of water - vegetated buffer zones around crops, riparian buffers to slow entry into open water (stream or irrigation canal), manure management, grazing practices ...

January 4 2013: FDA proposes rules to “ensure water used in irrigation meets standards...”
Farm practices to control spread of disease are well known

Aflatoxins and other mycotoxins
Aflatoxins (aflatoxins are a subset of mycotoxins)

- Produced by *Aspergillus* fungus
- **Known** – hepatoxic & cause liver cancer in people
- **Known** in mammals to cause growth faltering and ↓ *in utero* growth (e.g. low birth weight)
- **Associated*** with lower birth weight, growth, stunting, and wasting in children
- **Associated*** with lower CD4 and higher viral loads (e.g. worse immunity) in people with HIV
- **Widespread exposure** in sub-Saharan Africa, SE Asia; maize, peanuts, many other crops.

*Some criticize these studies for only being “associative” - but it is *unethical* to give aflatoxins to people. Prospective studies of exposure and outcomes are needed to show “causation.”*
Gong et al (BMJ, 2002) showed that **stunting** and weight for age was inversely related to blood **aflatoxin levels** in Gambia (p < 0.001, R² 0.37).
Cassava being dried on the ground: note green/yellow fungal discoloration

Photo: J K Griffiths  Kamwenge, Uganda December 2012
Aflatoxins II

• Contamination occurs in the field; promoted by poor post-harvest storage (excess moisture).
• Passed *in utero* and in breast milk to children
• Complementary foods (e.g. baby foods such as porridge made from maize) is frequently contaminated – as are milk, eggs, chickens, animal meats...
• Note: in foods introduced when infants are weaned
Ingested Aflatoxin Inhibits Protein Synthesis Found in Staple Foods; Breast Milk; Dairy and Poultry; not Destroyed by Cooking

Impaired Tight Junctions

Altered Intestinal Architecture

Reduced Barrier Function Leakage of Gut Contents

Systemic Immune Activation

Inhibition of Gut Regeneration

Glucose /Galactose Malabsorption

This looks like environmental enteropathy!

GROWTH FALTERING

Poor populations:
- Will likely eat aflatoxins in foods
- Many will have environmental enteropathy and live without good water or sanitation
- Lacking WASH and barriers to fecal contamination, they will have a different spectrum of gut bacteria than people with good WASH
Aspergillus spp. + moisture + warm temperature = Aflatoxin formation

Aflatoxin ingestion, duodenal uptake - Metabolites bind to DNA, proteins – can measure in blood, urine, tissues

Immunosuppression

Maize, groundnuts
Key staple crops

Enteropathy – permeable intestine with documented increased nutrient needs, state of chronic inflammation

Microbiome – less diverse, abnormal nutrient utilization by flora

Agricultural interventions

Leaky Inflamed Intestine (EE)

WASH interventions

Nutrition interventions

Diet, Societal Conditions

Diet: poor diversity, inadequate caloric & micronutrient intake, leading to immunosuppression

Pathogen exposure: Widespread food, water, environment contamination

Clinical Manifestations:
Cycle of repeated infections
Worsening nutritional status – stunting, underweight, IUGR
Take-Home: healthy growth requires:

- Adequate, varied nutrition with enough calories, micronutrients, and vitamins
- The absence of environmental toxins such as aflatoxins
- A clean environment which prevents environmental enteropathy, with its chronic inflammation and higher nutritional needs
- A normal gut microbiome which does not starve its host of nutrients and promote weight loss
Thanks!

Questions: jeffrey.griffiths @ tufts.edu

Photo: JK Griffiths Tanzania 2008