Household Air Pollution and Chronic Disease Among the Bottom Billion

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Tackling the Endemic Non-Communicable Diseases of the Bottom Billion
Harvard University, March 3, 2011
What NCD risk factor is shared by all billion people in the bottom billion?

- Diet?
- Physical inactivity?
- Smoking?
- Appropriate infectious agents?
- No
- So ubiquitous, in fact, that it is one of the best quick indicators of poverty?
Households Using Solid Cooking Fuels

% of HH Exposed to HAP
- < 5
- 6 - 20
- 21 - 50
- 51 - 75
- 76 - 93
- No Data

For 2005, CRA-10 preliminary
Proportion of Household Meals Cooked by Fuel Type in India

2005 NFHS
Road Map

• Intro – what’s wrong with biomass smoke?
• COPD – several new meta-analyses
• Lung cancer – new meta-analyses for both biomass and coal smoke [not further discussed].
• Cataracts/opacity – a major burden
• LBW – new meta-analysis, life-long chronic risks?
• Cardiovascular disease – interpolation backed up by physiological evidence
• “Epidemiologic” transition – do NCD risks rise with development?
Woodsmoke is natural – how can it hurt you?

Or, since wood is mainly just carbon, hydrogen, and oxygen, doesn’t it just change to CO₂ and H₂O when it is combined with oxygen (burned)?

Reason: the combustion efficiency is far less than 100%
Energy flows in a well-operating traditional wood-fired Indian cooking stove

A Toxic Waste Factory!!

Typical biomass cookstoves convert 6-20% of the fuel carbon to toxic substances

- Into Pot: 2.8 MJ (18%)
- In PIC: 1.2 MJ (8%)
- Waste Heat: 11.3 MJ (74%)

PIC = products of incomplete combustion = CO, HC, C, etc.

Source: Smith, et al., 2000
Toxic Pollutants in Biomass Fuel Smoke from Simple (poor) Combustion

- Small particles, CO, NO₂
- Hydrocarbons
  - 25+ saturated hydrocarbons such as n-hexane
  - 40+ unsaturated hydrocarbons such as 1,3 butadiene
  - 28+ mono-aromatics such as benzene & styrene
  - 20+ polycyclic aromatic hydrocarbons such as benzo(α)pyrene
- Oxygenated organics
  - 20+ aldehydes including formaldehyde & acrolein
  - 25+ alcohols and acids such as methanol
  - 33+ phenols such as catechol & cresol
  - Many quinones such as hydroquinone
  - Semi-quinone-type and other radicals
- Chlorinated organics such as methylene chloride and dioxin

Source: Naheer et al, J Inhal Tox, 2007
Health-Damaging Air Pollutants From Typical Woodfired Cookstove in India.

Typical Health-based Standards

- Carbon Monoxide: 150 mg/m³
  - Best single indicator
  - IARC Group 1 Carcinogens

- Particles: 3.3 mg/m³
  - 0.1 mg/m³

- Benzene: 0.8 mg/m³
  - 0.002 mg/m³

- 1,3-Butadiene: 0.15 mg/m³
  - 0.0003 mg/m³

- Formaldehyde: 0.7 mg/m³
  - 0.1 mg/m³

Wood: 1.0 kg Per Hour in 15 ACH 40 m³ kitchen

Typical Indoor Concentrations
Household Air Pollution Comparative Risk Assessment, 2011
Preliminary Estimates for India

Balakrishnan et al., in prep

Estimated 24-h PM$_{2.5}$ for solid-fuel-using households

~400 ug/m$^3$ mean
EPA standard
= 15ug/m$^3$
WHO AQG
= 10 ug/3
First person in human history to have her exposure measured doing one of the oldest tasks in human history in Kheda District, Gujarat, India in 1981.

Exposures seem to be high in a large vulnerable population. But what are the health effects?
Cognitive Impairment?
ALRI/Pneumonia (meningitis)
Asthma?
Low birth weight
Stillbirth
Cognitive Impairment?
Asthma?
Birth defects?

Chronic obstructive lung disease
Cancer (lung, NP, cervical, aero-digestive)
Blindness (cataracts, opacity)
Tuberculosis?
Heart disease*
Blood pressure ST-segment
*Interpolated

Diseases for which we have epidemiological studies - 2011
Biomass Smoke and COPD: Meta-analysis

- Summary RR estimates calculated using both fixed effects and random effects models
- Heterogeneity among studies assessed using general variance-based methods
- Publication bias assessed using funnel plot, Eggers and Begg’s tests

<table>
<thead>
<tr>
<th>Exposure Assessment Used for Analysis</th>
<th># of Final Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Type</td>
<td>19</td>
</tr>
<tr>
<td>Coal Only</td>
<td>7</td>
</tr>
<tr>
<td>Wood Only</td>
<td>6</td>
</tr>
<tr>
<td>Stove Type</td>
<td>2</td>
</tr>
<tr>
<td>Years Exposed</td>
<td>5</td>
</tr>
<tr>
<td>Urban v. Rural</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outcome Assessment</th>
<th># of Final Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronic Bronchitis, clinical definition</td>
<td>20</td>
</tr>
<tr>
<td>COPD, FEV₁/FVC &lt;0.70</td>
<td>4</td>
</tr>
<tr>
<td>Previous Physician Diagnosis</td>
<td>4</td>
</tr>
</tbody>
</table>
**Forest Plot for All Studies Included in Meta-analysis**

- Random effects model was used to account for significant heterogeneity between studies  \( X^2=150.329, df=29 \) (\( p=0.000 \))

- Overall effect measure for all studies, OR=2.140 (1.777, 2.577)
Risk of COPD: Vented vs. unvented coal stoves

Xuan Wei County, China, retrospective cohort, 1976-1992, 20,453 subjects, 81% added chimneys

Cataracts

- Major burden of disease in developing countries
- In South Asia, 2.8% of total DALYs in 2005
- Half that of ischaemic heart disease
- Roughly same as TB or stroke
- Greater than COPD or maternal conditions
- Women suffer 40% more than men
HAP and cataract: biological plausibility

- Cataracts have several known risk factors: UV, diabetes, tobacco smoke.
- Napthalene, a prevalent product of incomplete biomass combustion, is a reactive oxidative species (ROS) causing oxidative stress & damage to the eye.
- Cataract outcomes have been shown in rabbits and cows with prolonged exposure or under high doses.
- Recent study in Nepal shows exposure-response with biomass smoke exposure and lens opacity, a preclinical indicator of cataracts.
### Summary of 7 (of 9 total) studies

#### Studies adjusted for smoking (random effects)

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>ES (95% CI)</th>
<th>Weight</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saha (2005)</td>
<td>2.41 (0.906, .42)</td>
<td>10.23</td>
<td></td>
</tr>
<tr>
<td>Pokhrel (2004)</td>
<td>1.90 (0.99, 3.62)</td>
<td>14.93</td>
<td></td>
</tr>
<tr>
<td>Sreenivas (a) (1999)</td>
<td>0.37 (0.02, 6.69)</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Sreenivas (b) (1999)</td>
<td>1.82 (1.14, 2.92)</td>
<td>17.91</td>
<td></td>
</tr>
<tr>
<td>Ughade (1998)</td>
<td>4.14 (2.69, 6.37)</td>
<td>18.58</td>
<td></td>
</tr>
<tr>
<td>Badrinath (1996)</td>
<td>4.90 (2.83, 8.49)</td>
<td>16.57</td>
<td></td>
</tr>
<tr>
<td>Mohan (1989)</td>
<td>1.62 (1.14, 2.30)</td>
<td>19.86</td>
<td></td>
</tr>
<tr>
<td><strong>Overall (I-squared = 71.3%, p = 0.002)</strong></td>
<td><strong>2.45 (1.61, 3.73)</strong></td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:** Weights are from random effects analysis.
Pathways Relating Household Smoke Exposures and Low Birth Weight

- Indoor Cooking Smoke
  - Particulate Matter
    - Maternal Lung Disease
      - Reduced O2 Delivery to Placenta
        - Reduced O2 Content of Maternal Blood
          - Reduced O2 Transport Across Placental and Fetal Uptake
            - Preterm Delivery
              - Impaired Fetal Growth
                - Reduced O2 Content of Maternal Blood
                  - Maternal Lung Disease
                    - Reduced Nutrient Intake
                      - Child and Adult Ill-health
                        - Low Birth Weight
**Pooled birth weight difference (low minus high exposure): Adjusted estimates**

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Lower Exposure</th>
<th>Higher Exposure</th>
<th>Mean Difference</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Total</td>
<td>Mean</td>
</tr>
<tr>
<td>Boy 2002</td>
<td>2,835</td>
<td>533</td>
<td>357</td>
<td>2,772</td>
</tr>
<tr>
<td>Mishra 2004</td>
<td>3,271</td>
<td>1,448</td>
<td>766</td>
<td>3,096</td>
</tr>
<tr>
<td>Siddiqui 2008</td>
<td>2,812</td>
<td>404</td>
<td>80</td>
<td>2,730</td>
</tr>
<tr>
<td>Thompson 2005</td>
<td>2,805</td>
<td>579</td>
<td>366</td>
<td>2,723</td>
</tr>
<tr>
<td>Tielsch 2009</td>
<td>2,819</td>
<td>453</td>
<td>646</td>
<td>2,715</td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>2215</td>
<td></td>
<td></td>
<td>11740</td>
</tr>
<tr>
<td></td>
<td></td>
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All estimates: +96.6g (68.5, 124.7)
Excluding self-reports +93.1g (64.6, 121.6)
Chimney Stove Intervention to Reduce Long-term Woodsmoke Exposure Lowers Blood Pressure among Guatemalan Women

John P. McCracken, Kirk R. Smith, Murray A. Mittleman, Anaité Díaz, Joel Schwartz

(Published in Environmental Health Perspectives, July 2007)
Study Design

• Study population
  – Eligible: Women ≥ 38 years, cooking daily
  – Excluded: pregnant, breastfeeding

• Two follow-up periods
  – Randomized trial period (7/03-12/04)
  – Echo-intervention period (3/04-3/05)

Personal PM$_{2.5}$

SBP and DBP
### Between-Groups Results During Randomization

<table>
<thead>
<tr>
<th>Number of subjects (measures)</th>
<th>Adjusted mean difference*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control group</td>
<td>Intervention group</td>
</tr>
<tr>
<td>SBP 71 (111)</td>
<td>49 (115)</td>
</tr>
<tr>
<td>DBP 71 (111)</td>
<td>49 (115)</td>
</tr>
</tbody>
</table>

* Adjusted for age, body mass index, daily temperature, season, day of the week, time of day, use of wood-fired sauna, household electricity, an asset index, ever smoking, and secondhand tobacco smoke exposure
### Before-and-After Results

<table>
<thead>
<tr>
<th></th>
<th>Number of subjects (measures)</th>
<th>Adjusted mean difference*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial period</td>
<td>Echo-intervention</td>
</tr>
<tr>
<td>SBP</td>
<td>55 (88)</td>
<td>55 (65)</td>
</tr>
<tr>
<td>DBP</td>
<td>55 (88)</td>
<td>55 (65)</td>
</tr>
</tbody>
</table>

* Adjusted for age, body mass index, daily temperature, season, day of the week, time of day, use of wood-fired sauna, household electricity, an asset index, ever smoking, and secondhand tobacco smoke exposure
Heart Disease and Combustion Particle Doses

Smith/Peel (2010), “Mind the Gap” based on Pope et al. (2009)
Argument from consistency across combustion particle exposures for CVD

- Fine combustion particles are best measure of risk in each setting and seem to have similar effects per unit mass across the four source types
  - Three are mainly biomass
  - Outdoor air pollution contains significant biomass particles
  - Probably difference by outcome, however – e.g., LBW and lung cancer may be related to other components as well
- Remarkable consistency across 3 orders of magnitude of dose measured in mg/day of PM$_{2.5}$
- Where household air pollution has no direct epi data, seems reasonable to interpolate for outcomes where there are well established effects at both lower and higher doses.
Indian National Biomass Cookstove Initiative – Dec 2, 2009

• “Our aim is to achieve the quality of energy services from cookstoves [for all Indian households] comparable to that from other clean energy sources such as LPG.”

Analysis of total health benefits of 150 million advanced stoves introduced over 10 years in India

Ischaemic Heart Disease
Chronic Obstructive Pulmonary Disease
Health Benefits Upon Completion, 2020

- Remaining ALRI, IHD, COPD DALYs in 2020: 83%
- Avoided DALYs: 17%

- Avoided COPD DALYs: 9%
- Avoided IHD DALYs: 3%
- Avoided ALRI DALYs: 5%
Global Burden of Disease Database and Comparative Risk Assessment

Previous version, 2004, found 1.6 million premature deaths for HAP for just three outcomes.

Being completely updated
For 2011 release

For household air pollution:
New exposure assessment modeling
New outcome estimates based on meta-analyses
ALRI, COPD, Lung Cancer
Low birth weight, cataracts, cardiovascular
The Classic Epidemiological Transition

Infectious Diseases

Non-Communicable Diseases

Mortality Rates

Time
Disease Categories

• I - Traditional, Communicable
  – Infectious, maternal, perinatal, nutritional

• II - Modern, Non-communicable
  – Cancer, heart, neuro-psychiatric, chronic lung, diabetes, congenital

• III - Injuries, Non-Transitional
  – Unintentional
    • Motor vehicle, poisoning, falls, fire, drowning
  – Intentional
    • Suicide, violence, war
Classic Epi Transition

• I. Infectious diseases decline during development
• II. Chronic disease rise during development
• III. Injuries show no pattern during development and are thus “non-transitional”
• Test using GBD databases – only coherent global database for mortality and morbidity
• From Smith/Ezzati, 2005.
Classic Mortality Transition

Income Group

- Low
- Lower Middle
- Upper Middle
- High
- World

Fraction of Total

I - "Infectious"  II - "Chronic"  III - Injuries
Mortality Transition - Age Adjusted

Deaths per thousand

Income Group

Low

Lower Middle

Upper Middle

High

World

I - "Infectious"  II - "Chronic"  III - Injuries
Epidemiological Transition - Age Adjusted

- **Low Income Group**
  - DALYs per thousand: 168, 129, 37

- **Lower Middle Income Group**
  - DALYs per thousand: 46, 111, 28

- **Upper Middle Income Group**
  - DALYs per thousand: 32, 120, 25

- **High Income Group**
  - DALYs per thousand: 9, 87, 12

- **World**
  - DALYs per thousand: 98, 112, 29

Legend:
- I - "Infectious"
- II - "Chronic"
- III - Injuries
Epi Transition: Updated

• In terms of actual age-adjusted impact on populations, all classes of disease decline during development
  – I. Declines dramatically at every level
  – II. Declines slowly, but with little decline seen across middle income regions
  – III. Declines in a similar way to II and thus is not “non-transitional”

• Better to be rich for all major types of ill-health, although there are exceptions for individual diseases
Global Burden of Disease from Top 10 Risk Factors
plus selected other risk factors

- Underweight
- Unsafe sex
- Blood pressure
- Tobacco
- Alcohol
- Unsafe water/sanitation
- Child cluster vaccination*
- Cholesterol
- Lack of Malaria control*
- Indoor smoke from solid fuels
- Overweight
- Occupational hazards (5 kinds)
- Road traffic accidents*
- Physical inactivity
- Lead (Pb) pollution
- Urban outdoor air pollution
- Climate change

2004 CRA

Percent of All DALYs in 2000
Many thanks

Publications and presentations available at my website:
http://ehs.sph.berkeley.edu/krsmith/

Or just Google “Kirk R. Smith”