Impact of an Indoor Cookstove Intervention on Blood Pressure and Measures of Systemic Inflammation

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Cookstoves and Indoor Air Pollution

- More than half the world’s population worldwide utilizes biomass fuel and coal for heating and cooking

- Incomplete combustion of biomass fuels with poor ventilation generates high concentrations of indoor air pollution

- Complex mix of pollutants (PM, CO)

- Global burden of disease based on respiratory disease; cardiovascular disease research limited (Smith and Peel, EHP, 2010)
Global Noncommunicable Diseases — Where Worlds Meet

K.M. Venkat Narayan, M.D., Mohammed K. Ali, M.B., Ch.B., and Jeffrey P. Koplan, M.D., M.P.H.

The 10 Leading Risk Factors for Death, According to Income Level, 2004.*

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Deaths (millions)</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>World</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. High blood pressure</td>
<td>7.5</td>
<td>12.8</td>
</tr>
<tr>
<td>2. Tobacco use</td>
<td>5.1</td>
<td>8.7</td>
</tr>
<tr>
<td>3. High blood glucose level</td>
<td>3.4</td>
<td>5.8</td>
</tr>
<tr>
<td>4. Physical inactivity</td>
<td>3.2</td>
<td>5.5</td>
</tr>
<tr>
<td>5. Overweight and obesity</td>
<td>2.8</td>
<td>4.8</td>
</tr>
<tr>
<td>6. High cholesterol level</td>
<td>2.6</td>
<td>4.5</td>
</tr>
<tr>
<td>7. Unsafe sex</td>
<td>2.4</td>
<td>4.0</td>
</tr>
<tr>
<td>8. Alcohol use</td>
<td>2.3</td>
<td>3.8</td>
</tr>
<tr>
<td>9. Childhood underweight</td>
<td>2.2</td>
<td>3.8</td>
</tr>
<tr>
<td>10. Indoor smoke from solid fuels</td>
<td>2.0</td>
<td>3.3</td>
</tr>
<tr>
<td><strong>Low-income countries</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Childhood underweight</td>
<td>2.0</td>
<td>7.8</td>
</tr>
<tr>
<td>2. High blood pressure</td>
<td>2.0</td>
<td>7.5</td>
</tr>
<tr>
<td>3. Unsafe sex</td>
<td>1.7</td>
<td>6.6</td>
</tr>
<tr>
<td>4. Unsafe water and poor sanitation and hygiene</td>
<td>1.6</td>
<td>6.1</td>
</tr>
<tr>
<td>5. High blood glucose level</td>
<td>1.3</td>
<td>4.9</td>
</tr>
<tr>
<td>6. Indoor smoke from solid fuels</td>
<td>1.3</td>
<td>4.8</td>
</tr>
<tr>
<td>7. Tobacco use</td>
<td>1.0</td>
<td>3.9</td>
</tr>
<tr>
<td>8. Physical inactivity</td>
<td>1.0</td>
<td>3.8</td>
</tr>
<tr>
<td>9. Suboptimal breast-feeding</td>
<td>1.0</td>
<td>3.7</td>
</tr>
<tr>
<td>10. High cholesterol level</td>
<td>0.9</td>
<td>3.4</td>
</tr>
</tbody>
</table>

The 10 leading causes of death by broad income group, 2004

<table>
<thead>
<tr>
<th>Low-income countries</th>
<th>Deaths in millions</th>
<th>% of deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower respiratory infections</td>
<td>2.94</td>
<td>11.2</td>
</tr>
<tr>
<td>Coronary heart disease</td>
<td>2.47</td>
<td>9.4</td>
</tr>
<tr>
<td>Diarrheal diseases</td>
<td>1.81</td>
<td>6.9</td>
</tr>
<tr>
<td>HIV/AIDS</td>
<td>1.51</td>
<td>5.7</td>
</tr>
<tr>
<td>Stroke and other cerebrovascular diseases</td>
<td>1.48</td>
<td>5.6</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease</td>
<td>0.94</td>
<td>3.6</td>
</tr>
<tr>
<td>Tuberculosis</td>
<td>0.91</td>
<td>3.5</td>
</tr>
<tr>
<td>Neonatal infections</td>
<td>0.90</td>
<td>3.4</td>
</tr>
<tr>
<td>Malaria</td>
<td>0.86</td>
<td>3.3</td>
</tr>
<tr>
<td>Prematurity and low birth weight</td>
<td>0.84</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Diseases for which there are epidemiologic studies:

- ALRI/ Pneumonia (meningitis)
- Asthma
- Low birth weight
- Early infant death
- Cognitive Impairment?

Chronic obstructive lung disease
- Interstitial lung disease
- Cancer (lung, NP, cervical, aero-digestive)
- Blindness (cataracts, trachoma)
- Tuberculosis
- Heart disease?
Brook et al. Circulation 2010

**Blood**
- PM or constituents in the circulation
  - UFP, soluble metals
  - Organic compounds
- Vasoconstriction
- Endothelial dysfunction
- PM-mediated ROS
- BP
- Atherosclerosis
- Platelet aggregation

**Vasculature**
- Endothelial cell dysfunction/vasoconstriction, ↑ROS
- Atherosclerosis progression/plaque vulnerability
  - Thrombogenicity (e.g. tissue factor)

**Metabolism**
- Insulin resistance, dyslipidemia, impaired HDL function

**Blood**
- Coagulation, thrombosis; ↓ fibrinolysis (e.g. PAI-1)

**Systemic Oxidative Stress and Inflammation**
- Cellular inflammatory response (↑ activated WBCs, platelets, MPO)
  - Cytokine expression/levels (↑ IL-1β, IL-6, TNF-α)
  - ET, histamine, cell microparticles, oxidized lipids; ↓ anti-oxidants

**Vasculature**
- Vasoconstriction
  - Endothelial dysfunction
  - Neural-mediated ROS
  - BP

**Blood**
- Platelet aggregation

**Heart**
- HRV
- Heart rate
- Arrhythmia potential

**ANS imbalance**
- ↑ SNS / ↓ PSNS

**ANS**

**Bronchioles/Alveoli**
- PM and/or constituents transmitted into blood
- Pulmonary oxidative stress & inflammation
- Activation of lung ANS reflex arcs

**Blood**
- Sub-acute & Chronic
- "Systemic spill-over"

**Brook et al. Circulation 2010**
Primary Objective

Evaluate the relationship of change in stove type and change in pollution levels (indoor PM$_{2.5}$, indoor and personal carbon monoxide) from Year 1 to Year 2 with changes in cardiovascular and respiratory endpoints.
Pilot Study Location

- El Fortin, community outside of Granada, Nicaragua
Study Partners

• Trees, Water & People (Fort Collins, CO)

• Casa de la Mujer (Granada, Nicaragua)
Intervention Design

Baseline Assessment
(Exposure and health assessment with traditional open fires)

Intervention
(Eco-Stoves or EcoFogón)

12 Month Follow-up
(Repeat exposure and health assessments; 9-12 months after intervention)

Summer 2008

Summer 2009

Colorado State University
Study Population

- 123 non-smoking, primary female cooks
  - Using traditional open fires at baseline
  - Kitchen area - at least 3 walls
  - Willing to buy subsidized improved stove after baseline measurements
Exposure Assessment
(Sub-sample)

- 48-hour indoor PM$_{2.5}$ (UCB particle monitor)
- 48-hour indoor CO (Draeger Pac 7000)
- 48-hour personal CO (Draeger Pac 7000)
- Housing and ventilation survey
Health Endpoints

• Lung Function
  – Piko-1 Peak Flow Meter
    • Forced Expiratory Volume in 1 second
    • Peak Expiratory Flow

• Symptoms questionnaire

• Blood Pressure

• Heart Rate
Health Endpoints – Dried Blood Spots

• Ideal for field conditions in developing countries
  – Less invasive
  – Minimal post-collection processing
  – Can be stored at room temp

• CRP, SAA, sICAM, sVCAM, IL1-β, IL6, IL8, TNF-α (Mesoscale Multiplex Kits)
  – David Diaz-Sanchez, Jackie Carter; US EPA
## Baseline Population Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD) or N (%)</th>
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<tbody>
<tr>
<td><strong>(n=123)</strong></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>35.4 (16.2)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>28.1 (6.7)</td>
</tr>
<tr>
<td>Overweight/Obese (BMI ≥ 25)</td>
<td>85 (68%)</td>
</tr>
<tr>
<td>Obese (BMI ≥ 30)</td>
<td>44 (35%)</td>
</tr>
<tr>
<td>Education (years)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>33 (27%)</td>
</tr>
<tr>
<td>1-6</td>
<td>60 (49%)</td>
</tr>
<tr>
<td>7+</td>
<td>30 (24%)</td>
</tr>
<tr>
<td>Hypertension (SBP&gt;140 or DBP&gt;90)</td>
<td>24 (19%)</td>
</tr>
<tr>
<td>Exposure to second-hand smoke</td>
<td>42 (33%)</td>
</tr>
</tbody>
</table>
Baseline, cross-sectional analysis: Increase in systolic blood pressure per IQR increase in pollution measure (PM$_{2.5}$: 1.2mg/m$^3$; indoor CO: 24 ppm; personal CO: 2ppm) (Clark et al. IJOEH 2011)
Mean 48-hour average PM$_{2.5}$
(25$^{\text{th}}$, 75$^{\text{th}}$ percentiles)

![Bar chart showing mean 48-hour PM$_{2.5}$ levels for different groups with reduction percentages and p-values.](chart.png)
Limitations

• Small sample size
• One-time measurement
• No control arm
• Mixed use of open fires and stoves
• Exposure reduction sufficient??
Study Challenges

- ~50% adoption
- Round-bottom pots
- Materials/weather
- Maintenance
- Inappropriate amount of firewood
- Competing needs in community
Unconstrained & Unprompted "Dislikes" of the EcoStove

- No problems, 33
- Bad materials, 18
- Chimney damaged, 8
- Water leaks from chimney, 6
- Doesn't get hot enough, quickly enough, 7
- Gets too hot, 3
- Too much ambient heat, 3
- Smoke escapes, 3
- Difficult to light, 3
- Not sturdy, 1
- Difficult to clean plancha, 2
- Needs a lot of maintenance, 1
Unconstrained & Unprompted "Likes" of the EcoStove

- Can cook multiple items at once, 80
- Less wood (fuel) use, 51
- Better food / cooks well, 19
- No / Less smoke, 113
- Can start and leave unattended, 2
- Quick to heat w/o the plancha, 4
- Takes up less space, 2
- More comfortable (ergonomics), 4
- Easy to start or use, 6
- Tortillas / can cook food directly on it, 22
- Pans / walls are cleaner, 24
- Better health for kids, 4
- Better health, 8
- Stays hot / warm for long time, 10
- Heats up fast & cooks quickly, 56
- Likes it was a gift, 2
- Likes everything, 8
- Likes nothing, 2
- It's pretty, 8
Summary of Findings

- 77% reduction in PM$_{2.5}$
- 72% reduction in indoor CO
- 62% reduction in personal CO
- Small reduction in mean systolic blood pressure
  - Consistent with other studies
  - Larger reduction among obese subjects, older subjects (4-6 mmHg)
- Additional ongoing work
  - Additional analyses and validation of blood spot samples
  - Examination of lung function tests and symptoms between year 1 and 2 and barriers to adoption
ACKNOWLEDGMENTS:

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• Trees, Water & People

• El Fortin Participants

• Casa de la Mujer volunteers