Association between Long-term Exposure to Outdoor Air Pollution and Mortality in China: a Cohort Study

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Outline

• Background

• Methods

• Results and discussion

• Conclusion
“Pollution in China” – by Guang LU

Background
Background

Estimated PM$_{10}$ Concentration in World Cities (pop=100,000+)

[Map showing estimated PM$_{10}$ concentration around the world.]

Source: World Bank
Annual $\text{PM}_{10}$ levels in 31 provincial capitals of China
($\mu g/m^3$, 2008)
Background

Chinese burden of disease from top 10 risk factors plus selected other risk factors

Smith et al., 2005. Derived from WHO data
A summary of outdoor air pollution epidemiologic studies in China

• **Short-term exposure studies:**
  – Time-series/case crossover studies
    • Single-city analysis: Beijing, Hong Kong, Shanghai, Shenyang, Taiyuan, Wuhan, etc.
    • Multi-city analysis: PAPA, CAPES
  – Panel study: Beijing Olympics

• **Long-term exposure study**
  – Cross-sectional study: several
  – Cohort study: **NONE** previously

• **Intervention study**
  – Beijing Olympics
  – Hong Kong
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- **Methods**
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- Conclusion
CNHS-Air Study

• **China National Hypertension Survey (CNHS)**
  – Baseline survey in 1991
  – Follow-up visit in 1999
  – 158,666 participants in 17 provinces of China
    (including both urban and rural areas)

• **CNHS-Air**: a retrospective cohort analysis of outdoor air pollution and mortality in China
  – 70,947 *urban* participants in 31 Chinese cities
Method

Previous findings from the CNHS cohort

Body Weight and Mortality Among Men and Women in China

Major Causes of Death among Men and Women in China

The prevalence of obesity is increasing at an unprecedented rate among men and women around the world. It is estimated that more than 1 billion adults worldwide are overweight (body mass index ≥ 25.0) and more than 300 million are obese (body mass index ≥ 30.0). The prevalence of obesity and overweight has increased dramatically in recent decades, particularly in developing countries. This increase is attributed to changes in diet, physical activity, and lifestyle factors.

We documented 23,001 deaths in 1,209,151 people from follow-up. The mortality rates in this study were 23.0 per 100,000 persons/year among men and 21.3 per 100,000 persons/year among women. The leading causes of death were malignant neoplasms (40%), accidents (15%), and cerebrovascular disease (10%). The mortality rates differed significantly by age, sex, and body mass index.

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Health Outcome

- Death (Y/N & follow-up time; ICD 9)
  - All-cause non-accidental mortality
  - Cardiovascular mortality
  - Respiratory mortality
  - Lung cancer mortality
  - Other cause of cancer (control)
Air pollution exposure

- **Period:** 1991-1999
- **Pollutants:** TSP, SO$_2$, NO$_x$ (PM$_{10}$/PM$_{2.5}$/NO$_2$/O$_3$ not available)
- **ZIP code linking residential address to nearest air monitoring station**
Covariates

- **Baseline examination in 1991**
  - Age, sex, BMI, physical activity, education, alcohol intake (never, former and current drinker), and hypertension
  - Smoking status (current, former and never smoker), age at starting to smoke, years smoked, cigarettes per day
Statistical analysis

- Proportional hazards regression models, using SAS version 9.1
- Adjusted for a wide range of covariates
- Single-pollutant & multi-pollutant models
- Stratified analyses by sex, smoking, obesity, and education
Outline

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• Results and discussion
• Conclusion
Results

Descriptive analysis

- 8,319 deaths out of 70,947 subjects
### Descriptive analysis

Deceased subjects were:

- older
- more likely to be male or current smokers
- had less physical activity, and higher prevalence of hypertension

<table>
<thead>
<tr>
<th></th>
<th>Total (n=70,947)</th>
<th>Death (n=8,319)</th>
<th>Non-death(n=62,628)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>55.8 (10.5)</td>
<td>67.1 (10.6)</td>
<td>54.3 (9.6)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.6 (3.7)</td>
<td>23.0 (4.3)</td>
<td>23.7 (3.6)</td>
</tr>
<tr>
<td>Sex (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>51.5</td>
<td>56.5</td>
<td>50.9</td>
</tr>
<tr>
<td>Female</td>
<td>48.5</td>
<td>43.5</td>
<td>49.1</td>
</tr>
<tr>
<td>Physical activity (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>53.2</td>
<td>63.5</td>
<td>52.0</td>
</tr>
<tr>
<td>Medial</td>
<td>26.2</td>
<td>27.7</td>
<td>25.9</td>
</tr>
<tr>
<td>High</td>
<td>20.6</td>
<td>8.8</td>
<td>22.1</td>
</tr>
<tr>
<td>Smoking status (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>63.1</td>
<td>58.2</td>
<td>63.7</td>
</tr>
<tr>
<td>Past</td>
<td>2.7</td>
<td>4.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Current</td>
<td>34.2</td>
<td>37.1</td>
<td>33.9</td>
</tr>
<tr>
<td>Alcohol intake (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>19.3</td>
<td>18.7</td>
<td>19.4</td>
</tr>
<tr>
<td>Education level (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>18.8</td>
<td>32.2</td>
<td>17.1</td>
</tr>
<tr>
<td>High</td>
<td>38.0</td>
<td>23.6</td>
<td>39.8</td>
</tr>
</tbody>
</table>
Descriptive analysis

- Between 1991-1999, the averaged annual concentrations were 289 µg/m³ for TSP, 74 µg/m³ for SO₂, and 50 µg/m³ for NOₓ.
Results

Descriptive analysis

- **TSP**: $\downarrow 5\%$
- **SO$_2$**: $\downarrow 35\%$
- **NO$_x$**: $\uparrow 28\%$
Results

% increase of deaths associated with 10μg/m³ increase in air pollutants’ concentrations

<table>
<thead>
<tr>
<th>Cause of death</th>
<th>TSP</th>
<th>SO₂</th>
<th>NOₓ</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-cause</td>
<td>0.2</td>
<td>1.9</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>(-0.1, 0.5)</td>
<td>(1.4, 2.3)</td>
<td>(0.4, 2.4)</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>0.8</td>
<td>3.1</td>
<td>2.2%</td>
</tr>
<tr>
<td></td>
<td>(0.3, 1.4)</td>
<td>(2.3, 4.0)</td>
<td>(0.5, 4.0)</td>
</tr>
<tr>
<td>Respiratory</td>
<td>0.4</td>
<td>3.5</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>(-0.6, 1.3)</td>
<td>(2.0, 5.0)</td>
<td>(-0.1, 5.7)</td>
</tr>
<tr>
<td>Lung cancer</td>
<td>1.0</td>
<td>4.2</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>(-0.2, 2.2)</td>
<td>(2.2, 6.2)</td>
<td>(-1.0, 6.4)</td>
</tr>
<tr>
<td>Other causes of cancer</td>
<td>-0.1</td>
<td>0.2</td>
<td>-1.7</td>
</tr>
<tr>
<td></td>
<td>(-0.9, 0.7)</td>
<td>(-1.0, 1.4)</td>
<td>(-4.2, 0.8)</td>
</tr>
</tbody>
</table>
Discussion

PM health effects, compared with the ACS cohort study

**CNHS***: 10 µg/m³ increase of PM$_{2.5}$ was associated with
- 0.6% ↑ of total mortality
- 2.5% ↑ of cardiovascular mortality
- 1.2% ↑ of respiratory mortality
- 3.1% ↑ of lung cancer mortality

*: assuming PM$_{2.5}$/PM$_{10}$≈0.65 and PM$_{10}$/TSP ≈0.5

**ACS Cohort**: 10 µg/m³ increase of PM$_{2.5}$ was associated with
- 4% ↑ of total mortality
- 6% ↑ of cardiopulmonary mortality
- 8% ↑ of lung cancer mortality

Pope et al, *JAMA*, 2002
Establishment of Exposure-response Functions of Air Particulate Matter and Adverse Health Outcomes in China and Worldwide

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Kan et al, 2005
## Results

### Single vs. multi-pollutant models

<table>
<thead>
<tr>
<th>Model</th>
<th>Total mortality (95%CI)</th>
<th>Cardiovascular mortality (95%CI)</th>
<th>Respiratory mortality (95%CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TSP</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>single-pollutant</td>
<td>0.2 (-0.1, 0.5)</td>
<td>0.8 (0.3, 1.4)</td>
<td>0.4 (-0.6, 1.3)</td>
</tr>
<tr>
<td>adjusted for SO₂</td>
<td>0.0 (-0.4, 0.4)</td>
<td>0.8 (0.2, 1.4)</td>
<td>0.6 (-0.4, 1.7)</td>
</tr>
<tr>
<td>adjusted for NOₓ</td>
<td>0.0 (-0.4, 0.4)</td>
<td>0.8 (0.2, 1.4)</td>
<td>0.5 (-0.6, 1.6)</td>
</tr>
<tr>
<td><strong>SO₂</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>single-pollutant</td>
<td>1.9 (1.4, 2.3)</td>
<td>3.1 (2.3, 4.0)</td>
<td>3.5 (2.0, 5.0)</td>
</tr>
<tr>
<td>adjusted for TSP</td>
<td>1.8 (1.4, 2.3)</td>
<td>3.1 (2.2, 3.9)</td>
<td>3.4 (2.0, 4.9)</td>
</tr>
<tr>
<td>adjusted for NOₓ</td>
<td>1.8 (1.3, 2.3)</td>
<td>3.0 (2.2, 3.9)</td>
<td>3.3 (1.9, 4.9)</td>
</tr>
<tr>
<td><strong>NOₓ</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>single-pollutant</td>
<td>1.4 (0.4, 2.4)</td>
<td>2.2 (0.5, 4.0)</td>
<td>2.8 (-0.1, 5.7)</td>
</tr>
<tr>
<td>adjusted for TSP</td>
<td>1.4 (0.3, 2.5)</td>
<td>1.4 (-0.4, 3.3)</td>
<td>2.3 (-0.8, 5.4)</td>
</tr>
<tr>
<td>adjusted for SO₂</td>
<td>0.6 (-0.4, 1.7)</td>
<td>1.1 (-0.7, 2.9)</td>
<td>1.6 (-1.4, 4.7)</td>
</tr>
</tbody>
</table>
**Halves Yearly Mean Levels**

- **PM$_{10}$**
- **NO$_2$**
- **SO$_2$**
- **O$_3$**

**Fuel restriction on sulphur**

- 50% reduction in SO$_2$ after the intervention
- No change in other pollutants

**Discussion**

- Hong Kong, 1988 – 95

_Hedley et al., Lancet 2002_
Reductions In Deaths After Sulfur Restriction

Discussion

Hedley et al, Lancet 2002
## Discussion

### Comparison of SO$_2$’s health effect

<table>
<thead>
<tr>
<th></th>
<th>Our cohort study</th>
<th>HK intervention study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total mortality</td>
<td>1.9 (95%CI: 1.4, 2.3)</td>
<td>1.1 (95%CI: 0.5, 1.7)</td>
</tr>
<tr>
<td>Cardiovascular mortality</td>
<td>3.1 (95%CI: 2.3, 4.0)</td>
<td>1.0 (95%CI: 0.2, 1.9)</td>
</tr>
<tr>
<td>Respiratory mortality</td>
<td>3.5 (95%CI: 2.0, 5.0)</td>
<td>2.0 (95%CI: 0.8, 3.2)</td>
</tr>
<tr>
<td>Lung cancer mortality</td>
<td>4.2 (95%CI: 2.2, 6.2)</td>
<td>0.6 (95%CI: -0.4, 1.5)</td>
</tr>
</tbody>
</table>
## Results

### Stratified analysis

<table>
<thead>
<tr>
<th></th>
<th>TSP</th>
<th>SO$_2$</th>
<th>NO$_x$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Effect size</td>
<td>$p$</td>
<td>$p$ for interaction</td>
</tr>
<tr>
<td>Sex</td>
<td>Male</td>
<td>0.4 (0.0, 0.9)</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>0.0 (-0.5, 0.5)</td>
<td>0.97</td>
</tr>
<tr>
<td>Smoking</td>
<td>Never</td>
<td>0.1 (-0.3, 0.6)</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>Current/past</td>
<td>0.3 (-0.2, 0.8)</td>
<td>0.23</td>
</tr>
<tr>
<td>Obesity</td>
<td>BMI &lt; 25</td>
<td>0.4 (0.0, 0.8)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>BMI ≥ 25</td>
<td>0.1 (-0.6, 0.8)</td>
<td>0.77</td>
</tr>
<tr>
<td>Education</td>
<td>Low</td>
<td>0.1 (-0.2, 0.5)</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>0.5 (-0.3, 1.3)</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Never-smokers may be more susceptible to air pollution exposure!
Strengths & limitations

• **Strengths**
  – Large sample size
  – Detailed individual information on potential confounders

• **Limitations**
  – TSP and NO\(_x\) only
  – Air pollution exposure on the aggregated city level, rather than individual level
  – Lack of some potential confounders, e.g. diabetes
Conclusion

• First cohort study of air pollution health effects in China
• Significant associations between air pollutants and mortality from cardiopulmonary diseases and lung cancer
• Independent health risk of SO$_2$ in China
• Preliminary data of susceptible sub-population
Acknowledgement

• **Chinese Academy of Medical Sciences:** Dongfeng Gu
• **Fudan University:** Bingham Chen, Renjie Chen
THANK YOU FOR YOUR ATTENTION

kanh@fudan.edu.cn
Spatial distribution of air pollution emissions in China (2005)