Air pollution and the lung in children: the evidence for exposure and prevention measures

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University Children’s Hospital Basel
Overview

Background on pollutants outdoor and indoor pollutants

Outdoor air pollution during pregnancy and lung development (short term)

Outdoor air pollution during childhood and lung development (long term)
Overview

Outdoor:
Particulate matter (PM$_{10}$, PM$_{2.5}$, PM$_{1}$): carbon monoxide (CO), sulfur dioxide (SO$_2$), nitrogen oxide (NO$_2$), ozone (O$_3$), lead, polycyclic aromatic hydrocarbons (PAH)

Indoor:
Tobacco smoking, biomass, gas and other fuels for cooking and heating e.g. benzene, open fire places, furnishings, building materials
Background on outdoor air pollutants

PM: particulate matter / size in μm
- Origin mostly traffic and industry
- Rather homogenous spatial distribution

NO₂: nitric dioxide
- Origin mostly traffic
- Usually higher close to roads

Black carbon
- Pure carbon in several forms
- Origin incomplete combustion of fuel and biomass
Pollutants – spatial variation

Spatial variation – Utrecht (NL)  Spatial variation – Limpopo (South Africa)

Adapted from Schmidz et al. 2019. High resolution annual average air pollution concentration maps for the Netherlands, Scientific Data 6:190035

Pollutants – temporal variation in Switzerland

Temporal variation PM$_{2.5}$

Source: NABEL, results of national measurement stations, BAFU, EMPA, accessed 04.07.2021

Temporal variation NO$_{2}$
Pollutants – temporal variation in South Africa

Change in burned area (2005-2017)  
Change in NO₂ (2005-2017)

Hickman JE et al. Reductions in NO₂ burden over north equatorial Africa from decline in biomass burning in spite of growing fossil fuel use, 2005 to 2017, PNAS February 16, 2021 118 (7) e2002579118;
Air Pollution during pregnancy: mechanisms

- Dependent on stage of development
- Systemic effect on the mother:
  - reduced placental perfusion
  - reduced nutrient exchange
- Direct toxic effect through placental transfer of pollutants (e.g., nanoparticles)
- Proinflammatory/oxidative/hormonal stress effect
- Changes to the immune system development
- Changes to lung growth and development
- Genetic interactions/epigenetic effects
Air pollution during pregnancy

- **Environment**
  - Pollutants
    - Systemic inflammation
    - Endothelial dysfunction
    - Oxidative stress

- **Mother**
  - Direct effect of pollutants
  - Epigenetic changes

- **Placenta-Foetus**
  - Size of placenta ↓
  - Transport of O₂ and nutrients ↓

- **Newborn**
  - Mortality ↑
  - Malformation
  - Birth weight ↓
  - Lung function ↓
  - Immune System

Lee et al. *Epidemiology* 2011, reviewed in Slama et al. *Env Health Persp* 2008
adapted from Korten et al. *Ped Resp Rev* 2017
Infant lung function – Switzerland

241 term-born infants from the BILD cohort
Exposure towards PM$_{10}$ and NO$_2$ during pregnancy
Lung function at around 4 weeks

<table>
<thead>
<tr>
<th></th>
<th>Basic model</th>
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<th></th>
<th>Full model</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>coefficient</td>
<td>CI 95%</td>
<td>p Value</td>
<td>coefficient</td>
<td>CI 95%</td>
<td>p Value</td>
</tr>
<tr>
<td>Prenatal PM$_{10}$ and Minute ventilation [mL/min]</td>
<td>19.9</td>
<td>4.7 – 35.0</td>
<td>0.010</td>
<td>24.7</td>
<td>8.9 – 40.5</td>
<td>0.002</td>
</tr>
<tr>
<td>Prenatal NO$_2$ and eNO [ppb]</td>
<td>0.67</td>
<td>0.23 – 1.10</td>
<td>0.003</td>
<td>0.96</td>
<td>0.44 – 1.48</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
270 term-born infants from the Drakenstein Child Health Study

Exposure towards PM$_{10}$ during pregnancy and first year

<table>
<thead>
<tr>
<th></th>
<th>β-estimate (95% CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prenatal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRC (6 weeks)</td>
<td>$-1.9 (-4.5-0.7)$</td>
<td>0.160</td>
</tr>
<tr>
<td>Tidal volume (6 weeks)</td>
<td>$-0.4 (-1.3-0.6)$</td>
<td>0.419</td>
</tr>
<tr>
<td>FRC (1 year)</td>
<td>$-9.0 (-17.2-0.9)$</td>
<td>0.032#</td>
</tr>
<tr>
<td><strong>Postnatal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRC (1 year)</td>
<td>$-4.3 (-12.5-3.9)$</td>
<td>0.304</td>
</tr>
<tr>
<td>Tidal volume (1 year)</td>
<td>$-2.9 (-5.4-0.5)$</td>
<td>0.022#</td>
</tr>
<tr>
<td>LRTI (in the first year)</td>
<td>$0.0 (-0.3-0.4)$</td>
<td>0.799</td>
</tr>
</tbody>
</table>

Hüls et al. *ERJ* 2020
Childhood lung function – Spain

620 term-born infants from the INfancia y Medio Ambiente (INMA) cohort
Exposure towards benzene and NO₂ during pregnancy (second trimester)
Lung function at around 4.5 years, outcome FEV1

Eva Morales et al. Thorax 2015;70:64-73
Effects of long-term air pollution exposure during childhood

- Development of chronic lung problems in children
- Reduced lung function
  
- PMx → development of bronchitis, chronic cough, less from asthma
  
  (J Air Poll Control Assoc. 1982; 32: 937-942)
  (Schweiz: AJRCCM 1997; 155:1042-1049)
- Ozone → decline in lung function
  
  (Env. Research 1997; 72: 8-23)
- Road traffic (outdoor NO₂ + polycyclic aromatic hydrocarbons KWS, Diesel) correlated with asthma, hay fever, sensitivity to airborne allergens
  
  (ERJ 1997; 10: 2275-8)
  (Epidemiology 2000; 11: 64-70)
Lung development and prenatal exposure

adapted from Baraldi & Fillipone et al. *NEJM* 2007
‘Tracking’ of lung function during development


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Early childhood risk factors associated with functional development throughout life

Childhood risk factors for the decline in lung function in adulthood (28–73 yrs.)
- Infants born during winter
- Smoking mothers
- Older mothers

Dravda J et al. SAPALDIA PlosOne 2016; DOI 10.1371

Summarized in e.g. Postma D et al. Lancet 2015;385:899–909
Influence of long-term exposure on lung development

Air pollution in Poland is associated with reduced lung function during development

(e.g., Env Health Perspect 1999; 107: 669-674)

PM$_{10}$ particle concentration is inversely correlated to lung function development during childhood

(ERJ 2002; 19: 838-845)

Children who move away from polluted areas can return to normal lung functional development (and vice versa)

(AJRCCM; 2001; 164: 2067-72)

Improvement in air quality → reduced clinical symptoms

(AJRCCM; 2000; 161: 1930-36)
Early fife low level air pollution and lung functional growth

![Graph showing NO2 exposure levels (µg/m3) across pregnancy and early childhood years, with quartile markers for WHO guidelines.](image-url)

© UKBB Jakob Usemann

Usemann & Decrue et al. *Envir International* 2019
Early low level air pollution and lung growth

Effect of NO2 on FEV1 (in z-scores)

Time intervals

1. quartile
4. quartile
2.&3.quartile together

pregnancy, 1 year, 2 years, 3 years, 4 years, 5 years, 6 years

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Usemann & Decrue et al. Envir International 2019
Long-term effects on health development

Indoor air pollution and asthma

Respiratory insufficiency, Symptoms

Lung function

Birth

Alter

© UKBB Jakob Usemann
Commentary Frey U & Usemann J. Lancet Planet Health. 2019 Feb 5
Percentage of solid fuel use
Exposure levels of indoor air pollution

Switzerland: PM$_{2.5}$ ca 12.1 µg/m$^3$
**Indoor air pollution and asthma**

<table>
<thead>
<tr>
<th>First author [ref.]</th>
<th>Country</th>
<th>Fuel type</th>
<th>Sample size</th>
<th>Sample type</th>
<th>Diagnosis criteria</th>
<th>Effect size OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOHAMED [95]</td>
<td>Kenya</td>
<td>Biomass and clean fuel</td>
<td>77 cases and 77 controls</td>
<td>Children aged 9–11 yrs</td>
<td>Adapted from IUATLD</td>
<td>2.5 (2.0–6.4)</td>
</tr>
<tr>
<td>AZIZI [96]</td>
<td>Malaysia</td>
<td>Wood and kerosene</td>
<td>158 cases and 201 control</td>
<td>Children aged 1 month to 5 yrs</td>
<td>Hospital-based doctor diagnosed</td>
<td>1.4 (0.60–3.60) wood and 0.9 (0.50–1.60) kerosene</td>
</tr>
<tr>
<td>MELSOM [97]</td>
<td>Nepal</td>
<td>Biomass and clean fuel</td>
<td>121 cases and 126 control</td>
<td>Children aged 11–17 yrs</td>
<td>ISAAC criteria</td>
<td>2.2 (1.0–4.5)</td>
</tr>
<tr>
<td>MISHRA [98]</td>
<td>India</td>
<td>Biomass and clean fuel</td>
<td>38,955 subjects</td>
<td>Adults aged ≥60 yrs</td>
<td>Based on interviewee replying yes to asthma questionnaire</td>
<td>1.59 (1.30–1.94)</td>
</tr>
<tr>
<td>SCHEI [99]</td>
<td>Guatemala</td>
<td>Wood</td>
<td>1058 subjects</td>
<td>Children aged 4–6 yrs</td>
<td>ISAAC criteria</td>
<td>1.8 (0.76–4.19)</td>
</tr>
</tbody>
</table>
Conclusion

Associations between exposure towards air pollution and impaired lung development are relatively clear.

Stronger effects seem to exist during periods of fastest lung growth.

Reduction in exposure is associated with improved lung growth.

Exposure below WHO cut-offs still have negative effects on lung function.

Combination of risk factors attenuates detrimental effects on lung growth.

Modifiable risk factors should further be reduced.
Acknowledgements

Professor Prof Urs Frey, Basel
Professor Philipp Latzin, Bern
PD Dr. Kees de Hoogh & Professor Martin Röösli from Swiss TPH Basel

Thank you very much for your attention
Air Pollution and the Lung in Children
Prevention Measures

Rebecca Nantanda

PATS & ERS Paediatric Webinar

Tuesday 13th July 2021
Common sources of air pollution
Why intervene?

• Air pollution has life long implications (intra-uterine life – adulthood)

• Growing lungs (and other body organs) are very vulnerable to effects of air pollution
  Impact on overall growth and development and the potential of affected children

• Air pollution is directly linked to killer diseases
  50% of pneumonia deaths linked to air pollution

• Reducing air pollution leads to improvement in lung function
How to protect children from air pollution

- Invest in sustainable cleaner energy sources
- Reduce on fossil fuel combustion
- Minimize children’s exposure to polluted air
- Improve air pollution monitoring and its link with children’s health
- Strengthen children’s overall health increased resilience to effects of air pollution
Approach to interventions

- Reduce emissions
- Reduce concentrations
- Reduce exposure

Improvement in health
Association of Improved Air Quality with Lung Development in Children

W. James Gauderman, Ph.D., Robert Urman, M.S., Edward Avol, M.S., Kiros Berhane, Ph.D., Rob McConnell, M.D., Edward Rappaport, M.S., Roger Chang, Ph.D., Fred Lurmann, M.S., and Frank Gilliland, M.D., Ph.D.
THE RESPIRE TRIAL: Guatemala highlands

534 households with a pregnant woman or infant randomized to receive a chimney stove or retain the open fire

Primary outcome: incidence of pneumonia in children

Results

• Non-significant reduction in incidence of physician-diagnosed pneumonia
• Significant reduction in physician-diagnosed severe pneumonia (RR 0.67; 95% CI 0.45 to 0.98)

A cleaner burning biomass-fuelled cookstove intervention to prevent pneumonia in children under 5 years old in rural Malawi (the Cooking and Pneumonia Study): a cluster randomised controlled trial

Kevin Mambwe, Chifundo B Ndombelo, Andrew W Nourje, Julita Malava, Cynthia Katundu, William Weston, Deborah Havens, Daniel Pope, Nigel Bruce, Meleki Nyambele, Dukulzi Konga, Anmol Cumpin, Jonathan Grigg, Johni Holmes, Stephen B Gordon

Summary

Background WHO estimates exposure to air pollution from cooking with solid fuels is associated with over 4 million premature deaths worldwide every year including half a million children under the age of 5 years from pneumonia. We hypothesised that replacing open fires with cleaner burning biomass-fuelled cookstoves would reduce pneumonia incidence in young children.

Methods We did a community-level open cluster randomised controlled trial to compare the effects of a cleaner burning biomass-fuelled cookstove intervention to continuation of open fire cooking on pneumonia in children living in two rural districts, Chikhwawa and Karonga, of Malawi. Clusters were randomly allocated to intervention and control groups using a computer-generated randomisation schedule with stratification by site, distance from health centre, and size of cluster. Within clusters, households with a child under the age of 4–5 years were eligible. Intervention households received two biomass-fuelled cookstoves and a solar panel. The primary outcome was WHO Integrated Management of Childhood Illness (IMCI)-defined pneumonia episodes in children under 5 years of age. Efficacy and safety analyses were by intention to treat. The trial is registered with ISRCTN, number ISRCTN59448623.

Findings We enrolled 10,750 children from 8,626 households across 150 clusters between Dec 9, 2013, and Feb 28, 2016. 10,543 children from 8,470 households contributed 15,991 child-years of follow-up data to the intention-to-treat analysis. The IMCI pneumonia incidence rate in the intervention group was 15.76 (95% CI 14.89–16.63) per 100 child-years and in the control group 15.58 (95% CI 14.72–16.45) per 100 child-years, with an intervention versus control incidence rate ratio (IRR) of 1.01 (95% CI 0.91–1.13; p=0.80). Cooking-related serious adverse events (burns) were seen in 19 children; nine in the intervention and ten (one death) in the control group (IRR 0.91 [95% CI 0.37–2.23]; p=0.83).

Interpretation We found no evidence that an intervention comprising cleaner burning biomass-fuelled cookstoves reduced the risk of pneumonia in young children in rural Malawi. Effective strategies to reduce the adverse health effects of household air pollution are needed.

Funding Medical Research Council, UK Department for International Development, and Wellcome Trust.
Rwanda: High efficiency wood burning stove

- 2174 children, 5934 episodes of ARI
- Primary outcome – caregiver reported ARI
- Measured personal exposure for the cooks and child
- 25% reduction in prevalence of ARI, statistically significant PR=0.75 (0.60-0.93), p=0.009 (broad definition of pneumonia)
- No statistically significant difference – DHS – defined pneumonia, current pneumonia
- No statistically significant difference in mean PM2.5
- Decline in clean cookstove use from 81.2% to 64.4%
- Increase in use of traditional stove use from 24.1% to 49.4%

LPG use in the pilot study in India: HAPIN trial

Enrolled 41 women
   No previous use of LPG,
   Gestation weeks 9 to <20 weeks

Design: Before and after study

Intervention: Free of cost LPG, 100% adherence

Measurements:
Personal, kitchen and outdoor PM$_{2.5}$
baseline, 1 and 2 months
  • Kitchen=93% reduction in mean PM$_{2.5}$
  • Personal =78% reduction

Sambandam S, et al BMC Public Health 2020
Participants: 180 rural women aged 25-64 years

Intervention package: Stove, LPG delivery for 1 year, Education and behavioural change messaging

Assessment: BP, PEF, Respiratory symptoms (SGRQ), PM$_{2.5}$, CO, BC

Adherence assessed using temperature loggers

Primary outcomes
Differences in lung function and respiratory symptoms

Results
• LPG used in 98% of the days
• No difference in lung function and respiratory symptoms

Checkley W, et al. AJRCCM 2021
Feasibility and acceptability of a midwife-led health education strategy to reduce exposure to biomass smoke among pregnant women in Uganda, A FRESH AIR project

Rebecca Nantanda, Shamim Buteme, Sanne van Kampen, Lucy Cartwright, Jill Pooler, Andy Barton, Lynne Callaghan, Jean Mirembe, Grace Ndeezi, James K. Tumwine, Bruce Kirenga & Rupert Jones
Educational interventions: Midwife-led project in Uganda

Key findings

- Improvements in knowledge about risks of biomass smoke
- Changes made- keeping away from smoke, burying refuse
- Intent to change
- Buy solar panels, clean cookstoves
- Put chimneys on the kitchen
- Major barrier - Poverty
## Policy initiatives

<table>
<thead>
<tr>
<th>Country/Year</th>
<th>Intervention</th>
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<tbody>
<tr>
<td>UK</td>
<td>Standards and implementation of fuel quality initiated by The Quality Assured Fuel Scheme. National campaign to encourage uptake</td>
</tr>
<tr>
<td>South Africa</td>
<td>Encouraged investments in renewal energy through various funds, tax allowances and deductions</td>
</tr>
<tr>
<td>Namibia</td>
<td>Public campaign on forest conservation-reduction of fire incidences by 70%</td>
</tr>
<tr>
<td>Chile</td>
<td>Ministry of Environment- exchange of old stoves with new clean cookstoves</td>
</tr>
<tr>
<td>Rwanda</td>
<td>Banned non-biodegradable plastic bags -reduction in amount of burnt plastics</td>
</tr>
</tbody>
</table>
Urban planning
• Gazetted areas for industries
• Structural designs and operations that minimize industrial emissions
• Provision for active transport

Personal strategies
• Limit physical exertion outdoors on high pollution days
• Minimize use of highly polluted areas/roads
• Air quality alert systems

• How clean does the air need to get for health benefits to be seen?
• Cohort studies in Africa to document the impact of sustained air pollution exposure reduction and lung health
• Rigorous and methodologically strong studies with clear underlying behavioural theories and practices
• Evaluate early life origin of disease in relation to biomass smoke exposures in utero and early childhood
• Government-led initiatives in air quality monitoring, air quality management policies and how these impact of lung health outcomes
Behavioural change interventions to improve adherence to clean cooking

Formative research key findings
• Perceived disadvantage of solid fuel stoves
• Family influence on cooking decisions
• Heating needs
• Previous awareness and experience with LPG
• Traditional cookware and stoves used in the cooking
• Traditional foods and preferred stove for preparing them

DETERMINANTS OF LUNG FUNCTION AMONG INFANTS IN UGANDA: A BIRTH COHORT STUDY

IMPALA STUDY GROUP

The NIHR Global Health Research programme supports high-quality applied health research for the direct and primary benefit of people in low and middle-income countries, using UK Aid from the UK Government.
Children’s Air Pollution Profiles in Africa (CAPPA)

ACACIA study Group
Conclusions

• Interventions to reduce air pollution and improve children’s lung health – mixed results

• Further research
  ▪ Technologies - Low cost designs that are acceptable and sustainable
  ▪ Incorporate behavioural change in studies on air pollution
  ▪ Policies
  ▪ Affordability, access to desired stoves/fuel, stove maintenance/ lifespan

• Consider in-depth evaluations to provide insight into fidelity, feasibility, quality of implementation and causal mechanisms
THANK YOU