Reduced lung function due to biomass smoke exposure in young adults in rural Nepal

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ABSTRACT

This study aimed to assess the effects of biomass smoke exposure on lung function in a Nepalese population addressing some of these methodological issues from previous studies.

We carried out a cross-sectional study of adults in a population exposed to biomass smoke and a non-exposed population in Nepal. Questionnaire and lung function data were acquired along with direct measures of indoor and outdoor air quality.

Ventilatory function (FEV₁, FVC, FEF₂₅₋₇₅) was significantly reduced in the population using biomass across all age groups compared to the non-biomass using population, even in the youngest (16-25) age group [mean FEV₁ (95% CI) 2.65 (2.57-2.73) vs. 2.83 (2.74-2.91), p=0.004]. Airflow obstruction was twice as common among biomass users compared to liquefied petroleum gas users (8.1% vs. 3.6%, p<0.001) with similar patterns for males (7.4% vs. 3.3%, p=0.022) and females (10.8% vs. 3.8%, p<0.001) based on lower limit of normal. Smoking was a major risk factor for airflow obstruction but biomass exposure added to the risk.

Exposure to biomass smoke is associated with deficits in lung function, an effect which can be detected as early as late teenage years. Biomass smoke and cigarette smoke have additive adverse effects on airflow obstruction in this setting.
About half the world’s population, mostly from the developing countries use solid fuels (biomass and coal) [1] as their main energy source resulting in potentially harmful exposures. Chronic obstructive pulmonary disease (COPD) is as much a disease of developing countries as of the developed world [2] with the World Health Organization (WHO) estimating that approximately 700,000 of the 2.7 million global deaths due to COPD are attributable to indoor air pollution from solid fuels [3] particularly in women. A meta-analysis has reported a three-fold increase in risk for COPD in populations exposed to solid-fuel smoke, the effect being dependent on fuel type with those exposed to wood smoke having the greatest effect (relative risk 4.3) compared to animal dung/crop residues (relative risk 2.5) and coal/charcoal (relative risk 1.5 to 1.8) [4]. Studies from developing countries including Nepal have shown higher prevalence of respiratory symptoms and reduced lung function associated with solid fuel use both in children and in adults, particularly in women involved in cooking [4]. However, many of these studies from Nepal have been suffering from inadequate methodology, including the use of non-validated questionnaires, poor quality spirometry results, lack of a non-exposed population, compromised validity of exposure assessment and limited control for confounding factors such as cigarette smoking. All of these shortfalls could have potentially resulted in over-estimation of effect sizes.

This cross-sectional study aimed to use validated objective and subjective measures of lung disease to test the hypothesis that exposure to the products of biomass fuel use is associated with reduced lung function and increased airflow obstruction when compared with exposure to liquefied petroleum gas (LPG). A secondary aim was to relate real time particle exposures to lung function.
METHODS

Sampling frame and participants

Between April 2006 and February 2007, biomass-exposed population (98.9% used wood) were sampled from two village development committees (VDCs) in the Kathmandu Valley. Four wards (out of nine) in each VDC were randomly selected and all individual in the selected wards aged 16 years or above were eligible to be included if they met the inclusion criteria (no doctor diagnosed respiratory or cardiovascular health problems and also agreeing to 24-hour exposure monitoring in their homes). The non-exposed population (98.4% used LPG) were selected from six wards (from a total of 35) in the Kathmandu municipality: three selected randomly on the periphery of ring road and the other three selected from 1-2 km inside the ring road. The non-exposed sample lived around 10-12 km to the south-west of the biomass-exposed sampling sites. All locations were between 1300 m to 1600 m above sea level. The majority of the houses in the biomass exposed sample were constructed from a mud-based material with a thatched or tiled roof whereas in the non-exposed areas, houses were made of brick and cement. The non-exposed population lived in close proximity to main roads, while the biomass-exposed lived in rural areas with negligible traffic or industrial activities. However, the latter regularly travelled to the areas near the ring road to sell their agricultural products in the early mornings (when traffic is minimal). The study protocol was approved by the Nepal Health Research Council. Written consent was obtained from all participants.

Sample size

As published lung function data in Nepal have been limited, sample size was calculated assuming a prevalence of COPD of 10% in the non-exposed and 20% in the exposed, the
latter being two times the reported prevalence in previous Nepalese studies [5, 6]. For an 80% power at 5% significance level and allowing for 10% dropout or refusal, a sample size of 396 women and 396 men in each exposure group was needed.

**Particle exposure measurement**

Full details have been reported elsewhere [7]. Levels of respirable dust and particulate matter with a diameter of 2.5 µm or less (PM$_{2.5}$) were measured over a 24 h period in most dwellings (n=490) using a photometric device (DustTrak 8520 and SidePak AM510, TSI Inc., Shoreview, MN, USA). All data obtained by the photometric devices were multiplied by calibration factor obtained using a standard gravimetric technique [7]. Indoor carbon monoxide (CO) levels over 24 h were measured by HOBO CO loggers (MicroDAQ, Contoocook, NH, USA). Mean 24 exposure data are expressed as geometric mean and geometric standard deviation unless indicated.

**Lung function**

All participants underwent spirometry using the EasyOne spirometer (ndd Medizintechnik AG, Zurich, Switzerland) at their homes in standing position in accordance with the latest American Thoracic Society/European Respiratory Society (ATS/ERS) guidelines [8] without the use of bronchodilator. Quality of the spirometry data were assessed in the UK by one of the co-authors (JA) by inspection of both volumetric and flow volume traces. Unacceptable traces were removed. The best of three reproducible values was used in the analysis. We defined airflow obstruction (AFO) as FEV$_1$/FVC less than the lower limit of normal (LLN) to minimise over- or under-diagnosis [9]. Predicted values were calculated by the reference equations from the European Community for Steel and Coal with a 10% reduction for non-Caucasians [9]. Height was measured by measuring tape and weight was measured without
footwear and very light clothing using a digital scale. For comparability with some previous studies, we repeated the analysis by redefining AFO as FEV$_1$/FVC of less than 70%.

**Questionnaire**

An interviewer-administered questionnaire was used to collect data on smoking, socio-economic status, kitchen characteristics, cooking details, literacy and history of fuel use.

**Statistical analysis**

Statistical analyses were performed using Stata (version 11, STATA, College Station, Texas, USA). Baseline demographic characteristics were compared between biomass exposed and non-exposed samples by regression for survey data taking into account the household clustering. Linear and logistic regression models were built to evaluate the effect of the use of biomass and the exposure levels on lung function indices and AFO, respectively. All known and potential risk factors not collinear with biomass use were routinely adjusted for to obtain regression coefficient ($\beta$), with robust variance estimates to allow for household clustering effect. In addition, we calculated three measures of biological interaction (on the additive scale): relative excess risk due to interaction (RERI); attributable proportion due to interaction (AP); and the Synergy index (SI), where in the absence of interaction, both RERI and AP = 0 and SI = 1 [10, 11]. A positive interaction indicates the combined effect of exposures is larger than the sum of the individual effects, and a negative interaction represents a smaller combined effect.

**RESULTS**

A total of 1648 participants were enrolled, of whom 1392 (656 men and 736 women) had valid spirometry and were used in analysis. Of these, 49.9% (n=695) were exposed to
biomass smoke and remaining 50.1% (n=697) used non-biomass (primarily LPG) for domestic purposes (Table 1). Biomass-exposed men and women were significantly shorter, weighed less and were more likely to be illiterate than the non-biomass using counterparts. The biomass-exposed groups had much lower annual incomes compared to the other (median US$ 744 vs. $2496, p<0.001) and had a higher proportion of current smokers, especially among women (Table 1).

Exposures

Across the dataset, the geometric mean of the 24 h indoor PM$_{2.5}$ concentrations in biomass using homes (455 µg/m$^3$, 95% CI: 426, 485 µg/m$^3$) was significantly greater than in LPG using homes (101 µg/m$^3$, 95% CI: 96, 106 µg/m$^3$, p<0.001). Indoor PM$_{2.5}$ concentrations in ventilated kitchens where biomass was burned (448 µg/m$^3$, 95% CI: 405, 495 µg/m$^3$) were significantly higher than where LPG was used either with ventilation (99 µg/m$^3$, 95% CI: 94, 104 µg/m$^3$, p<0.001) or without ventilation (120 µg/m$^3$, 95% CI: 99, 144 µg/m$^3$, p<0.001). The 24h time-weighted average CO concentrations measured in kitchens were significantly (p<0.001) higher where biomass fuel was used (13.4 ppm, 95% CI: 11.7, 15.4 ppm) compared to where LPG fuel was used (2.0 ppm, 95% CI: 1.9, 2.2 ppm).
Table 1: Demographic data of 1392 Nepalese adults aged ≥16 years according to type of fuel use, by sex

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Biomass</td>
<td>Non-biomass</td>
<td>p-value</td>
</tr>
<tr>
<td><strong>n</strong></td>
<td>326</td>
<td>330</td>
<td>0.636</td>
</tr>
<tr>
<td><strong>Age, years (SD)</strong></td>
<td>35.2 (16.7)</td>
<td>36.3 (14.9)</td>
<td>0.029</td>
</tr>
<tr>
<td><strong>Height, cm (SD)</strong></td>
<td>162.2 (7.3)</td>
<td>165.7 (6.7)</td>
<td>0.003</td>
</tr>
<tr>
<td><strong>Weight, kg (SD)</strong></td>
<td>52.8 (8.2)</td>
<td>62.5 (10.0)</td>
<td>0.005</td>
</tr>
<tr>
<td><strong>Body mass index, kg/m² (SD)</strong></td>
<td>20.0 (2.6)</td>
<td>22.8 (3.4)</td>
<td>0.015</td>
</tr>
<tr>
<td><strong>Literate, n (%)</strong></td>
<td>274 (84.1)</td>
<td>321 (97.3)</td>
<td>0.119</td>
</tr>
<tr>
<td><strong>Smoking status, n (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-smoker</td>
<td>181 (55.5)</td>
<td>210 (63.6)</td>
<td>0.012</td>
</tr>
<tr>
<td>Ex-smoker</td>
<td>26 (8.0)</td>
<td>56 (17.0)</td>
<td>0.197</td>
</tr>
<tr>
<td>Current smoker</td>
<td>119 (36.5)</td>
<td>64 (19.4)</td>
<td>0.119</td>
</tr>
</tbody>
</table>

P values were derived from regression analysis of survey data taking into account the clustering of household
**Lung function parameters**

In general, univariate analysis suggested that biomass smoke-exposed individuals had poorer lung function than the non-exposed. Deficits in FEV$_1$, FVC, FEV$_1$/FVC and FEF$_{25-75}$ were found in both men and women, across the age range ([Supplementary Table S1](#)). FEV$_1$, FEV$_1$/FVC and FEF$_{25-75}$ remained to be lower in biomass fuel-using participants even after adjusting for potential confounders including height, age, sex, body mass index (BMI), literacy, income, ever smoking history and environmental tobacco smoke exposure. Similar findings were obtained when the data were re-analysed after stratifying for sex ([Table 2](#)). In the youngest age group of 16-25 years, FEV$_1$ was 225 mL (95% CI 106, 344 mL, p<0.001) less, while FEF$_{25-75}$ was 510 mL/s (95% CI 263, 757 mL/s, p<0.001) lower in participants exposed to biomass smoke, having adjusted for confounders. However there was no significant association between FVC and biomass use. On the other hand, none of the lung function parameters measured was significantly associated with CO and PM$_{2.5}$ ([Table 2](#)).
<p>| TABLE 2: REGRESSION COEFFICIENTS (LUNG FUNCTION INDICES) AND ODDS RATIOS USING ROBUST VARIANCE ESTIMATES COMPARING USE OF BIOMASS FUEL WITH USE OF LPG STOVES (REFERENT CATEGORY) |</p>
<table>
<thead>
<tr>
<th>FEV₁</th>
<th>FVC</th>
<th>FEF₂₅-₇₅</th>
<th>FEV₁/FVC</th>
<th>AFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression coefficient β (95% CI)*</td>
<td>p-value</td>
<td>Regression coefficient β (95% CI)*</td>
<td>p-value</td>
<td>Regression coefficient β (95% CI)*</td>
</tr>
<tr>
<td>Use of biomass</td>
<td>-0.103</td>
<td>0.002</td>
<td>-0.045</td>
<td>0.224</td>
</tr>
<tr>
<td>PM (in mg/m³)</td>
<td>0.01</td>
<td>0.961</td>
<td>0.001</td>
<td>0.822</td>
</tr>
<tr>
<td>CO (in ppm)</td>
<td>-0.008</td>
<td>0.488</td>
<td>-0.004</td>
<td>0.698</td>
</tr>
<tr>
<td>Inadequate ventilation</td>
<td>-0.020</td>
<td>0.517</td>
<td>0.009</td>
<td>0.752</td>
</tr>
<tr>
<td>Sleeping in the kitchen</td>
<td>0.028</td>
<td>0.437</td>
<td>0.048</td>
<td>0.182</td>
</tr>
</tbody>
</table>

**COMBINED DATA FOR MEN AND WOMEN**

| Use of biomass | -0.103 | 0.002 | -0.045 | 0.224 | -0.355 | <0.001 | -2.881 | <0.001 | 2.06 | 0.014 |
| PM (in mg/m³) | 0.001 | 0.961 | 0.001 | 0.822 | -4.93 | 0.317 | -0.50 | 0.009 | 0.93 | 0.492 |
| CO (in ppm) | -0.008 | 0.488 | -0.004 | 0.698 | -3.16 | 1.16 | -0.26 | 0.01 | 0.90 | 0.245 |
| Inadequate ventilation | -0.020 | 0.517 | 0.009 | 0.752 | -3.24 | 0.10 | -0.01 | 0.01 | 0.19 | 0.492 |
| Sleeping in the kitchen | 0.028 | 0.437 | 0.048 | 0.182 | -0.016 | 0.839 | -1.36 | 1.06 | 1.02 | 1.00 |

**WOMEN DATA ONLY**

| Use of biomass | -0.074 | 0.046 | -0.034 | 0.393 | -0.304 | <0.001 | -2.586 | 0.002 | 2.38 | 0.067 |
| PM (in mg/m³) | -0.002 | 0.908 | -0.113 | 0.759 | -0.46 | 0.124 | -0.86 | 0.10 | 0.001 | 1.00 |
| CO (in ppm) | -0.005 | 0.174 | -0.002 | 0.627 | -1.70 | 1.87 | -0.013 | 0.214 | 0.001 | 0.098 |
| Inadequate ventilation | 0.002 | 0.956 | 0.013 | 0.770 | -0.042 | 0.597 | -1.97 | 0.113 | 0.017 | 0.060 |
| Sleeping in the kitchen | 0.015 | 0.755 | 0.021 | 0.660 | -0.003 | 0.977 | -2.68 | 2.208 | 0.097 | 0.950 |

**MEN DATA ONLY**

| Use of biomass | -0.012 | 0.070 | -0.055 | 0.330 | -0.397 | <0.001 | -2.95 | 0.001 | 1.74 | 0.199 |
| PM (in mg/m³) | 0.007 | 0.845 | 0.165 | 0.303 | -0.60 | 0.193 | -2.42 | 1.03 | 0.641 | 0.563 |
| CO (in ppm) | -2.79 | 0.993 | 0.003 | 0.415 | -0.006 | 0.316 | 0.186 | 0.051 | 0.067 | 0.260 |
| Inadequate ventilation | -0.047 | 0.300 | -0.004 | 0.982 | -0.17 | 0.050 | -2.72 | 0.265 | 0.106 | 0.515 |
| Sleeping in the kitchen | 0.026 | 0.613 | 0.060 | 0.290 | -0.044 | 0.672 | -2.37 | 0.851 | 0.354 | 1.79 |

FEV₁=Forced expiratory volume in one second, FVC=Forced vital capacity, FEF₂₅-₇₅=Forced expiratory flow 25-75%, FEV₁/FVC= Ratio of FEV₁ to FVC, AFO=Air flow obstruction based on lower limit of normal FEV₁/FVC= (LLN ratio for FEV₁/FVC > FEV₁/FVC), CI=confidence interval
* Adjusted for height, age, gender, literacy, BMI, income, ever smoking history ['Ever smoker' = at least 20 packs of cigarettes or 12 oz (360 grams) of tobacco in a lifetime, or at least one cigarette per day or one cigar a week for one year] and environmental tobacco smoke ['Yes' = regularly exposed to other people tobacco smoke where 'regularly' = on most days and nights]
Airflow obstruction (AFO)

The prevalence of AFO in the biomass smoke exposed (8.1%) was significantly higher than that in the non-biomass exposed group (3.6%) with similar findings for males (7.4% vs. 3.3%, p=0.022) and females (10.8% vs. 3.8%, p<0.001) separately (Supplementary Table S2). Those aged 16-25 years and exposed to biomass smoke (n=253) had a significantly higher prevalence of AFO compared to non-exposed individuals of the same age (n=223) regardless of smoking status (3.6% vs. 0.5%, p=0.018). When restricting to life-long non-smokers, AFO was also more common in the biomass smoke exposed group (5.2% vs. 1.8%, p=0.004).

Multivariate analysis (adjusted for height, age, gender, BMI, literacy, income, smoking history and environmental tobacco smoke) shows that AFO was significantly higher in biomass smoke exposed population compared to those using LPG fuel (Table 2). Similar magnitude of association was obtained when stratified for sex, although being non-statistically significant, possibly due to a lack of power. Re-defining AFO as FEV1/FVC<70% did not alter the conclusions.

Interaction

We did not find any positive interaction between smoking history and biomass smoke exposure but found some evidence of negative interaction for AFO between ever smoker and biomass smoke exposure (Male: RERI=-2.57, 95% CI -9.98, -4.83; Female: RERI=-2.70, 95% CI -0.857- 3.18) and also negative interaction in female for AFO between current smoker and biomass smoke exposure (RERI=-4.102, 95% CI -13.63, - 5.43). Nevertheless, none of them were statistically significant (Supplementary Table S3).
DISCUSSION

This is the first population-based study of lung function in Nepal studying two very distinct populations: biomass- and the non-biomass users. Different indices of lung function were significantly lower in both men and women in the biomass smoke exposed group compared to the non-exposed and this difference was evident even in the youngest age group studied (16-25 years), suggesting a possible detrimental effect of biomass smoke exposure on lung growth in early life. The prevalence of AFO in the biomass smoke exposed group was two times than that found in the non-biomass exposed and was higher in the youngest age group.

The prevalence of AFO based on LLN regardless of smoking status was 8.1% in the biomass smoke exposed group and 3.6% in the non-exposed participants, being higher in women than in men. Studies from Turkey [12], Nepal [13], China [14], Spain [15] and Columbia [16] have reported positive associations between biomass smoke exposure and COPD although the quantified risk varies across a wide range [4] of effect sizes. However, the odds ratio for AFO in the biomass smoke exposed population in this study was around half that found in a meta-analysis of studies of COPD in biomass smoke exposed populations (odds ratio for wood smoke exposure 3.96) [4]. This difference may be due to aspects of study design or the definition of airflow obstruction. Firstly, we used quality assured lung function testing, adhering strictly to the ATS/ERS guidelines [8]. Biomass smoke exposure is almost uniform in the rural areas in Nepal, “normal” lung function values, even if exist, would be difficult to interpret given the likely effects of this exposure on lung function. This can be addressed by comparing exposed with non-exposed populations but this has often been absent in previous studies. Secondly, relevant confounding factors have not always been addressed in previous work. In this respect, we have accounted for environmental tobacco smoke exposure (self-
AFO was related to smoking in the non-biomass smoke exposed population (8% in current smokers, 12% in ex-smokers and 2% in never smokers) while in the rural area smoking and biomass exposure appeared to have a multiplicative effect in terms of AFO. This coheres with earlier work from Nepal (24) which found significantly lower lung function in both smokers and non-smokers among rural, biomass smoke exposed dwellers compared to non-biomass smoke exposed urban dwellers. Our findings are qualitatively similar to previous work in Ecuador [17], India [18] and Turkey [19] where populations using biomass fuel had lower lung function compared to relatively clean fuel users irrespective of smoking status.

The deficit in FEF25-75 both in women and men is consistent with our previous finding from a pilot study [20] carried out in the same area. While FEF25-75 is not recommended in clinical practice for the diagnosis of small airways obstruction [21, 22], its deficit provides an additional evidence for the presence of AFO.

Our study has some limitations. For practical and clinical reasons post-bronchodilator lung function was not measured, hence we were not able to differentiate whether AFO was a manifestation of COPD or asthma. A further limitation is the near perfect concordance between the use of biomass fuel, lower socio-economic status and rural dwelling. Although it is likely that the associations reported here between rural dwelling and reduced lung function are a consequence of lifetime exposure to biomass smoke, it is not possible to rule out confounding by other closely associated influences such as diet [23], respiratory infection [24] and low birth weight [25], all closely associated with low socio-economic status. The
exposed population being slightly shorter compared to non-exposed could be the result of malnourishment during the development period and hence the lower lung function observed. We had anticipated that objective measures of indoor airborne pollution (CO and PM$_{2.5}$) would be able to clarify the issue, but only the association between FEF$_{25-75}$ and CO was significant ($p=0.027$). It is likely that a “one-off” measurement of indoor air pollution fails to quantify the effects of a lifetime of variable exposure to biomass fuel. Previous study has suggested large day to day variability of exposures exists within a home [26]. Our findings appear to suggest that repeated measurements of exposure for longer duration and also in different seasons are essential to understand the dose-response relationship. A detailed record of time activities along with measurements of exposure in different micro-environments such as kitchen, bedroom, living area, outdoor and workplace environments will be required to better quantify the exposures because static measurements only in the kitchen will not provide sufficient information to estimate the personal exposure with better accuracy. Ultimately these issues can only be resolved by interventional trials such as the work in Mexico showing significant attenuation of FEV$_1$ loss with the use of the improved cookstoves and fewer respiratory symptoms [27].

Occupational exposures also contribute to the development of AFO but the extent has not been assessed in this study. The biomass-exposed group recruited in the rural areas was exposed to dust and organophosphate pesticides from agricultural activities, the former being a recognised risk factor for airway inflammation [28] and the latter being purported to be linked with reductions in lung function [29]. On the other hand, urban dwellers who did not use biomass fuel were exposed to higher levels of ambient air pollution from traffic sources. Moreover, some of the current non-users had previously lived in rural areas and had thus been
exposed to biomass smoke. However, these effects would tend to reduce the comparative impact on lung function and AFO in this study.

Despite only few women smoke compared to men, lung function was consistently worse in women perhaps because women were more likely to do the cooking. Lung function in biomass smoke exposed, life-long non-smoking, and younger individuals (16-25 years) of both sexes was significantly lower compared to their non-exposed counterparts as was the prevalence of AFO. Rural dwellers are exposed to biomass smoke from birth and girls in Nepal start cooking regularly when they are 13-14 years old thus increasing their exposures at critical times in lung development. It is thus reasonable to assume that biomass smoke exposure could retard lung growth although other factors such as environmental tobacco smoke exposure and a diet deficient in nutrients [30] may also play a role. The fact that for rural dwellers smoking appeared to have less influence on lung function particularly in women may imply a swamping effect of biomass smoke.

We found evidence suggestive of negative multiplicative interaction between ever smoking and biomass smoke on AFO suggesting that possibly either survival effect or the combined effect of biomass and smoking is more than the individual effect of smoking and biomass but less than the multiple of biomass and smoking.

In summary, we have shown that exposure to biomass smoke results in a doubled risk of AFO in a biomass smoke exposed group population in Nepal after allowing for other factors but that cigarette smoking has an additive effect. The observation that these associations were evident by late teenage years suggests that biomass smoke exposure during childhood may impair lung growth.
Conflict of interest

All authors declare that they have no conflicts of interest

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