Ventilated cookstoves associated with improvements in respiratory health-related quality of life in rural Bolivia

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ABSTRACT

Background Household air pollution (HAP) from combustion of biomass fuels worldwide is linked to asthma, respiratory infections and chronic pulmonary diseases. Implementation of ventilated cookstoves significantly reduces exposure to HAP. However, improvements in concurrent respiratory health-related quality of life (HRQoL) have not been previously evaluated with a standardized questionnaire.

Methods The association between woodsmoke exposure and respiratory HRQoL outcomes was evaluated using an intervention study in a rural community in Bolivia. Indoor carbon monoxide (CO) levels from traditional stoves and from cookstoves with chimneys were analyzed alongside interview results of women heads-of-households using the St. George's Respiratory Questionnaire (SGRQ) in 2009 and 1-year post-intervention.

Results Pronounced improvements in respiratory HRQoL and significant reductions of household CO levels followed installation of ventilated cookstoves. Stove implementation yielded lower indoor CO values and correlated positively with improved SGRQ scores.

Conclusions This is the first use of a standardized respiratory HRQoL assessment to determine the impact of ventilated cookstove implementation on reducing HAP. This preliminary study utilizes the SGRQ as a valuable tool enabling analysis of these health effects in relation to other respiratory disease states.

Keywords biomass fuel, carbon monoxide, CO, household air pollution, respiratory health-related quality of life, St. George's Respiratory Questionnaire

Introduction

Nearly 2.7 billion people rely on biomass fuels (wood, crop residues, dung and charcoal) for their primary domestic energy needs.1–3 In many developing countries, burning of biomass accounts for almost one-half of domestic energy production and can reach as high as 95% in some countries.14,5 Biomass fuels are typically burned in open-pit fires or inefficient cookstoves without sufficient ventilation. This practice results in exposure to health hazards including particulate matter (PM) and carbon monoxide (CO) that are 10–20 times greater than World Health Organization air quality guidelines.6–10 Studies have shown that household air pollution (HAP) from indoor combustion of biomass fuels in developing countries is linked to acute respiratory infections, chronic obstructive pulmonary disease (COPD), asthma and other health problems.11–14 In 2010, global mortality due to HAP from solid fuels was estimated to be more than 3.5 million deaths per year.15

To date, no standard questionnaire has been used to evaluate respiratory health related to ventilated cookstove interventions. Standardized respiratory questionnaires provide insight into the effects that improved air quality have on health-related quality of life (HRQoL) in a manner that can be compared with other respiratory disease states and interventions. The St. George's Respiratory Questionnaire (SGRQ) is a well-established tool...
for quantifying health status in chronic pulmonary diseases and has been shown to correlate well with disability due to disease.\textsuperscript{16} It encompasses a broad range of respiratory diseases and has previously been used to measure HRQoL for industrial diseases such as pneumoconiosis.\textsuperscript{17} This study represents the first use of the SGRQ in ventilated cookstove interventions. While most questionnaires regarding respiratory health focus on identifying symptoms only, the SGRQ measures the overall respiratory HRQoL providing additional clinical insight.\textsuperscript{16} The SGRQ allows researchers to determine the impact of disease on a subject’s daily life and represents a valuable evaluation tool to assess the benefits of ventilated cookstove interventions.

Reducing exposure to HAP is one of the main goals of improved biomass cookstove implementation projects. However, due to logistical difficulties and long sampling periods, PM monitoring equipment can be problematic and expensive in stove implementation studies.\textsuperscript{18} This study used CO concentrations as a marker for woodsmoke exposure. CO passive diffusion tubes have been shown to be a reliable proxy for PM < 2.5 μm (PM\textsubscript{2.5}) in prior woodsmoke studies.\textsuperscript{11,18,19} In a recent review of woodsmoke exposure studies, 8-h averages for CO ranged from 1.2 to 60 mg/m\textsuperscript{3} \textit{[1–49 parts per million (ppm)]}.\textsuperscript{10} In contrast, National Ambient Air Quality Standards set by the US Environmental Protection Agency require that 8-h average CO concentrations of 10 mg/m\textsuperscript{3} not to be exceeded more than once per year.\textsuperscript{20}

\section*{Methods}

The study was conducted using a paired pre-test and post-test assessment of HRQoL and CO levels following installation of ventilated cookstoves. The research was conducted in the Acacio province of northern Potosí, Bolivia (altitude range 2900–3300 m). In this region, most women cook indoors over open-pit fires for 3–5 h per day without the benefit of a chimney. Cooking patterns do not vary seasonally, and while stoves provide heat to the kitchen, they are not used for this purpose. Traditional, clay cookstoves are placed in the corner of the kitchens (see Supplementary data for photo). The primary fuel source is hardwood trees. The primary language and culture of the region is Quechua, although some individuals also speak Spanish. Communities range in size from 8 to 60 households. The village of Tuquiza was selected for assessment based on the use of indoor biomass fuel for cooking and planned provision of improved cooking stoves with roofs and chimneys designed by the University of Washington chapter of Engineers without Borders (EWB). No other co-interventions occurred during the study period.

Fifty Yanayo cookstoves were provided to \textasciitilde 80\% of the households in Tuquiza in September and October, 2009. These stoves were provided to all households who wanted them, regardless of whether they chose to participate in the study. Only women who cooked indoors over open-pit fires and who reported their overall health as ‘ok’ or ‘good’ were eligible to be part of the study. Women who reported their health as ‘bad’ were questioned as to the reason for their poor health. If it was determined that the illness was unrelated to respiratory health but prohibited the women from taking part in daily activities, they were excluded from the study.

During the months of August and September, 2009, pre-implementation respiratory HRQoL assessments of the 31 women heads-of-households who elected to join this study were performed using the SGRQ. CO levels were assessed in each household for two consecutive 24-h periods prior to intervention. Between the initial assessment and the 1-year follow-up, 10 women dropped out of the study due to non-respiratory illness, death or re-location. In 2010, between the months of August and October, a post-implementation follow-up was performed for the remaining 21 women (35\% of the households) using the same SGRQ survey and CO level detection methods. One woman did not sufficiently complete the post-intervention questionnaire for analysis. In total, 20 subjects were analyzed in the paired pre- and post-intervention cohort.

The SGRQ is a well-established method to quantify health status in pulmonary diseases. The SGRQ includes questions related to symptoms (e.g. coughing, chest pain, etc.), activity (e.g. walking uphill, walking at a rapid pace) and impact (e.g. disrupted sleep, expectations of improvement in health) and weights each of these sections for a total score. Scores range from 0 to 100 for each SGRQ category with higher scores indicating poorer respiratory HRQoL than lower scores. The surveys were verbally translated from a validated Peruvian Spanish version of the SGRQ into Quechua by two bi-lingual interpreters during the face-to-face interview.\textsuperscript{21}

Gastec brand CO passive diffusion tubes were placed in the women’s households both pre- and post-intervention for 2 consecutive, roughly 24-h periods. The time of CO tube placement and collection were recorded. From these data, time-weighted-average values were calculated to find CO in ppm. The CO passive diffusion tubes were read blind and recorded onsite by two research associates, immediately following the sampling period.

The independent variables in this study were the implementation status of the Yanayo cookstove and the household CO levels. The dependent variable in the study was the resulting SGRQ scores (symptoms, activity, impact and total). These outcomes were compared pre- versus post-stove intervention. All 20 women in the cohort reported using their ventilated cookstoves as their sole cooking device following the
2009 intervention (see Supplementary data for additional study details).

Questionnaire results were analyzed with the SGRQ Analysis package for Microsoft Excel. Pre- and post-intervention outcomes were compared using Wilcoxon signed-rank tests. Spearman rank correlation tests were used to determine the relationships of SGRQ outcomes to exposures (CO concentrations, age) using XLSTAT (Addinsoft). Power analyses were performed using JMP software (SAS).

Results

Table 1 summarizes the results of the study in addition to the ages of the women in this study. Average CO levels and all categories of SGRQ scores were improved (lower) following the intervention. Detailed within-subject changes in each woman’s SGRQ results from pre-intervention to post-intervention are shown in Fig. 1. Improvement in a subject’s HRQoL is associated with a decrease in the scores from pre- to post-intervention, while a worsening of HRQoL is associated with an increase. After the intervention, women using Yanayo stoves with chimneys had significantly improved SGRQ scores than the pre-implementation scores of these same women using traditional cookstoves without chimneys. Table 2 describes the changes in the SGRQ and CO scores for individuals comparing post- to pre-implementation (negative scores are improvements). Overall, 85% (17/20) of the women in the study had improved total SGRQ scores, 75% (15/20) had improved activity and impact scores and 65% (13/20) had improved symptoms scores. While activity, impact and total SGRQ scores had statistically significant decreases following the stove intervention \( (P<0.002, P<0.002\) and \( P<0.001\), respectively), Symptoms scores were not significantly improved. However, a breakdown of questions contributing to the symptoms score shows that attacks of wheezing and severity and length of attacks of chest trouble were all significantly reduced post-implementation \( (P<0.04, 0.03\) and 0.007, respectively).

Pre- and post-intervention CO concentrations in Tuquiza confirmed the reduction of CO in all homes following implementation of Yanayo stoves. Prior to stove implementation, the average CO level was 10.8 ppm. Following the intervention, CO concentrations in households decreased, on average, to 20% of the pre-implementation levels \( (2.3\text{ ppm, } P<0.0001)\).

Changes in the individual subjects’ SGRQ scores were plotted versus changes in their households’ CO levels from pre- to post-intervention in Fig. 2. The Spearman rank coefficients and \( P \) values were also reported on each subfigure. For total scores, Spearman R value is 0.24 \( (P = 0.32)\), Activity R value is 0.23 \( (P = 0.32)\) and Impact R value is 0.42 \( (P = 0.7)\), Symptoms R value is \( -0.42\) \( (P = 0.1)\).

Discussion

Main findings of this study

In this study, the use of Yanayo cookstoves was associated with significantly better overall HRQoL and indoor CO levels than traditional stove use. Total, activity and impact HRQoL scores on the standardized SGRQ improved significantly following the use of the new stoves with chimneys. A positive correlation with CO change was also observed for these scores post implementation of the Yanayo stoves.

What is already known on this topic

A study by Ferrer et al. has reported mean SGRQ symptoms, activity, impact and total scores in healthy populations of women at 7.8, 14.8, 4.3 and 8.2 respectively. The women in the study represented a cross-section of ages, educations and socioeconomic statuses in Spain. A study of pneumoconiosis (due to inhalation of coal dust) in men in Hong Kong resulted in SGRQ scores for symptom, activity, impact and total scores of 38.0, 44.5, 34.2 and 39.4, respectively. In a review evaluating the health effects of woodsmoke exposure, Naheer et al. reported average daily CO values ranging from 1.2–60 mg/m\(^3\) \( (~0.97–48.6\text{ ppm})\). CO values from our study fall within this range.

Table 1 Age, pre-intervention SGRQ scores and pre-intervention CO levels

<table>
<thead>
<tr>
<th>Category</th>
<th>Pre-intervention</th>
<th>Post-intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age (years)</td>
<td>47.2 (42.2–54.2)</td>
<td>48.2 (43.2–55.2)</td>
</tr>
<tr>
<td>SGRQ scores (0–100)</td>
<td>58.2 (52.3–63.0)</td>
<td>35.3 (25.3–45.4)</td>
</tr>
<tr>
<td>Symptoms</td>
<td>51.8 (41.6–62.1)</td>
<td>42.4 (30.7–54.2)</td>
</tr>
<tr>
<td>Activity</td>
<td>68.4 (59.4–77.3)</td>
<td>40.7 (28.1–53.2)</td>
</tr>
<tr>
<td>Impact</td>
<td>54.3 (48.0–60.5)</td>
<td>29.9 (20.8–39.1)</td>
</tr>
<tr>
<td>Household CO level (ppm)</td>
<td>10.8 (8.9–12.7)</td>
<td>2.3 (1.6–3.0)</td>
</tr>
</tbody>
</table>

Notes:
- All 20 participants were non-smoking female heads-of-households of subsistence farming families interviewed during August and September of 2009 (pre-intervention) and again in September of 2010 (post-intervention).
- Lower SGRQ scores and household CO levels are considered preferable to higher ones.
What this study adds

According to the authors of the SGRQ, clinically significant improvements in health status of COPD patients were associated with a 4 point decrease in SGRQ total scores. While no clinical diagnosis of disease has been made in the present study, Total scores declined significantly, on average by more than 22 points. This is a clear indication of substantially improved HRQoL for women after implementation of Yanayo cookstoves ($P = 0.001$). It is interesting to note that symptoms scores, which are the only impact measured by most respiratory HRQoL studies, were not statistically significantly improved following the stove implementation. Despite this, a number of the specific questions related to Symptoms measurements did show statistically significant improvements within participants.

While improvements in HRQoL due to indoor stove use have been described in a recent study, our use of the standardized SGRQ allows for analysis of the severity of these effects in a manner that can be related to other disease states. Both healthy and pneumoconiosis populations have lower (better) SGRQ scores than the Tuquiza women prior to Yanayo stove intervention. It is likely that, in addition to respiratory disease presence, the differences in population, environment and limited access to medical care play a role in these variations.

At the time of the post-intervention surveys, Yanayo stoves with chimneys had been used by the participants for 1 year. While no stove use monitoring data is available, all participants destroyed their traditional stove upon receiving the Yanayo cookstove and began using their Yanayo cookstoves as their sole cooking apparatus.

### Table 2 Change in SGRQ scores

<table>
<thead>
<tr>
<th>△ SGRQ score</th>
<th>Mean change$^{a}$</th>
<th>P value (LSN)$^{b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>△Total</td>
<td>−22.8 (−33.2 to −12.5)</td>
<td>0.001 (7)</td>
</tr>
<tr>
<td>△Symptoms</td>
<td>−9.4 (−23.3 to 4.6)</td>
<td>0.225 (57)</td>
</tr>
<tr>
<td>△Activity</td>
<td>−27.7 (−40.3 to −15.1)</td>
<td>0.002 (8)</td>
</tr>
<tr>
<td>△Impact</td>
<td>−24.3 (−35.7 to −13.0)</td>
<td>0.002 (6)</td>
</tr>
</tbody>
</table>

$^{a}$Post-intervention score minus pre-intervention score.

$^{b}$LSN (least significant number). The sample size needed to prove statistical significance for each change in scores at an alpha of 0.05.

The actual sample size was 20 subjects.
This preliminary study using standardized HRQoL assessments to measure exposure and outcomes shows promising results suggesting that a large scale case-control study will provide even more definitive conclusions.

**Limitations of this study**

The Yanayo stoves were part of an intervention that included building a separate kitchen with corrugated metal roofing in which the ventilated cookstove was installed. This holistic intervention was aimed at reducing the CO and HAP in the homes. Thus, the stoves alone cannot be considered the sole cause of the improvements in HRQoL or CO reduction.

However, the ventilated cookstoves themselves could not have been installed in the traditional thatch roofed homes.

We found an association between woodstove implementation and improved HRQoL as measured by SGRQ activity, impact and total scores. Decreases in individual subjects’ SGRQ total, activity and impact scores following stove intervention were associated with concurrent decreases in CO in the households according to the Spearman rank correlations. While not statistically significantly correlated with the drastic CO reductions seen in the 1-year timeframe of this study, the correlations might be detectable in a longer case-controlled study. It is also possible that other factors influenced the relationship between quantitative measurement of CO levels and...
true personal exposure such as the placement of the monitor in the home, wind direction, backdraft from chimneys, changed seating positions and a woman's time away from the cookstove. While a positive correlation between reductions in CO and SGRQ activity, impact and total scores occurred, there was a weak suggestion of the opposite relationship for the SGRQ symptoms scores. One reason may be the small number of subjects. According to a retrospective power analysis, a follow-up study would require at least 79 participants to determine statistical significance ($P < 0.05$) of the symptoms scores. However, because statistically significant improvements occurred for other scores, it is also possible that the intervention had no effect on respiratory symptoms. This would agree with a previous HRQoL study that found large improvements in non-respiratory symptoms, such as eye irritation, but little change in respiratory symptoms following ventilated cookstove implementation.

As a paired pre-test post-test design, this preliminary study did not include non-intervention control subjects. It is therefore possible that the completion of the questionnaire a second time could account for the changes seen in the SGRQ scores. However, given the positive correlation with the CO readings taken in the subject's homes and the 1-year period between the tests it is unlikely that the changes in SGRQ scores are due to repetition of the questionnaire.

Finally, it is possible that education on the health effects of HAP may have influenced participants' answers to the SGRQ. As a self-reported measurement, participants could have artificially inflated or deflated their HRQoL, either consciously or unconsciously, during the study. Potentially, survey responses to the SGRQ could have been biased by a subject's desire to receive a stove or other further assistance. Participation in this study, however, was not required for obtaining a Yanayo stove, making this bias unlikely. Subjects did not receive the score results from either their pre- or post-intervention questionnaires, nor were there any ‘right’ or ‘wrong’ answers. Thus, it is unlikely that learning effects occurred during the study unless subjects felt that they ‘ought’ to have experienced changes due to the intervention. Of all the SGRQ categories, symptoms scores might be expected to be affected by potential learning effects as these could most easily be associated with reduction in HAP. However, symptoms were the only measurement that did not significantly improve.

Conclusions

Here, we report the first use of a validated respiratory HRQoL instrument, the SGRQ, to determine the impact of reducing HAP through the implementation of cooking stoves with chimneys. Women cooking on new Yanayo stoves had significantly better respiratory HRQoL than prior to the implementation when these same women cooked on traditional stoves. However, post-implementation HRQoL was still worse than that of healthy populations, and is instead, more similar to previous research findings in populations suffering from pneumoconiosis. The use of Yanayo stoves reduced air pollution exposures as measured by CO levels and was associated with an improvement in SGRQ scores. Our results suggest that HAP from poorly vented stoves may lead to detrimental effects on women's respiratory HRQoL, and may be ameliorated by improving stove technology and ventilation. The use of a larger case-controlled study following participants for a longer period will likely yield even further concrete evidence correlating HRQoL improvements with decreases in HAP.

As organizations expand their efforts to improve global health and indoor air quality, further research on the impact of ventilated cookstoves is necessary to ensure that both HAP and HRQoL are enhanced by these efforts. Because of its focus on HRQoL aspects beyond symptoms, the SGRQ presents a valuable evaluation tool to assess the benefits of ventilated cookstoves and to compare these to other respiratory disease interventions.

Supplementary data

Supplementary data are available at PUBMED online.

Acknowledgements

The authors would like to thank the women of Tuquiza who were the subjects of this study, Nathaniel Wilson for helping with data collection, the University of Washington chapter of EWB.

Funding

The Osberg endowment for providing partial funding support.

References

2 Ezzati M, Kammen D. The health impacts of exposure to indoor air pollution from solid fuels in developing countries: knowledge, gaps, and data needs. Environ Health Persp 2002;110:1057–68.


