Effect of an improved cookstove on indoor particulate matter, lung function and fuel efficiency of firewood users

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Abstract

Indoor air pollution increases morbidity and mortality of millions of lives especially among women and children in developing countries. A major source of indoor air pollution is biomass used as energy source during cooking. Improved cookstoves were therefore developed to reduce pollution from gases and particulate matter. The main objective was to assess the effect of an improved cookstove on indoor particulate matter concentration, lung function tests and fuel economy. A "before and after" study was carried out among 81 households who use firewood as source of fuel. Study area was Obiakpor Local Government Area of Port Harcourt. Results showed a total of 81 households were studied and all were females. Sixty two (77%) had at least secondary education while 8 (10%) had no formal education. The age range was 21 to 81years and few respondents (14.8%) were aware of improved cookstove. There was significant reduction (32%) in the mean particulate matter concentration when improved cookstoves were used as cooking utensil compared to when traditional stoves were used (P = 0.02). The lung function of the respondents also improved when using the improved cookstove. Families spent three times on firewood when cooking with traditional tripod stoves than when cooking with improved cookstoves. In conclusion awareness regarding improved cookstoves is still poor. Use of improved cookstoves reduces indoor particulate matter concentration and the amount spent on firewood. It is recommended that there should be increased awareness and enlightenment regarding improved cookstoves.

Keywords: cookstove; biomass; indoor air pollution, particulate matter

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Introduction

Indoor air pollution (IAP) is a common cause of morbidity and mortality especially in resource-poor communities. A significant source of IAP is the burning of fuels such as biomass in stoves. Over 3 billion people worldwide cook in their homes with biomass (WHO 2014). Cooking with this source of fuel exposes people to the toxic fumes which contain dangerous particulate matter (PM), carbon monoxide (CO), nitrogen oxides, formaldehyde, benzene, 1,3 butadiene, polycyclic aromatic hydrocarbons (such as benzo[a]pyrene) and other toxic pollutants from the fire wood smoke (WHO 2014) . Inhaling these pollutants is known to claim the lives of over 4 million people yearly world over (WHO 2014) and in some sub-Saharan African countries the particulates released during cooking are responsible for up to 780/1000 deaths resulting from lung cancer, ischaemic heart disease and cardiovascular diseases combined (Evans et al 2012).

Unfortunately, those who are mainly affected are the women and children who make up to 85% of these deaths due to their increased exposure in the cooking environment (Mishra 2003). Some of the early manifestations of exposure to IAP are rhinitis and asthma (an obstructive lung disease). Obstructive lung diseases that may result are diagnosed by performing a lung function test (FEV_1/FVC). Due to the associated health hazards of IAP attempts have been made to reduce its emissions. In developing countries where use of biomass as source of fuel is prevalent the high costs associated with developing stoves that will cut these emissions had remained a big challenge. However, in the past few years several improved cookstoves have been developed and studies have compared their efficacy, safety and emissions (Oanh et al. 2005; Bhattacharya et al 2002; Tsai et al 2003). One of such cookstoves is Envirofit. Incidentally, not much research has been carried out to ascertain the pattern of domestic biomass use, its performance in terms of quantity of firewood used for cooking and effect on respiratory (lung) functions of end users in Nigeria. This study objectives were therefore to compare the 24 hour mean levels of indoor particulate matter, lung function tests of firewood users and amount of firewood used before and during the use of Envirofit in households.

Materials and Methods

Study design

This was a “before and after” study that was carried out in 2012 to 2013 among people who cook with firewood. This study design approach was used in order to avoid many confounding variables that may occur if separate study and control groups were used e.g. due to different sizes, design and ventilation of kitchens. Study areas were the communities of Rumuomasi, Rumuezeolu, Rumuobiakani, Oginigba and Eneka; all in Obiakpor Local Government Area (LGA) of Rivers State, Nigeria. Any household in these communities whose only source of energy for cooking was firewood and gave informed consent was eligible for the study. Ethical permission was obtained from the Ethics Committee of University of Port Harcourt Teaching Hospital Ethics Committee while informed consent was obtained from each study participant.

Materials

A UCB Particle Monitor was used to collect data on $PM_{2.5}$ released during cooking with firewood (Household Environmental Monitor 2012). It is able to measure particles less than 2.5 µm in diameter (Chowdhury et al. 2007). Three questionnaires were also used: a general purpose structured interviewer administered questionnaire was used at baseline to obtain information on socioeconomic conditions, household characteristics, and health-related data. Indoor Air Pollution: Pre and Post-Monitoring Questionnaires (UCODEA/CEIHD/UC-Berkeley 2005) and UCB Particle Monitor Sampling Data Form (UCODEA/CEIHD/UC-Berkeley 2005) were used to collect data before and after the use of Envirofit –Improved cookstoves. The model of the Envirofit stove used in the study was the G – 3300 (Envirofit International 2012). Stanley 25 ® Tape Rules were used to measure the placing distance of the UCB monitor on the wall, as was specified in the UCB manual. A Digital portable spirometer (Brand named: Nicesound); Model Number LT-102 was used for in the study for spirometry and measurement of lung function.

Method

This involved pre-intervention, intervention and post-intervention stages. During the pre-intervention stage, two field-work consultants were engaged and briefed on the survey objectives and work plan. Out of a total of 441 households who cook with only firewood, 89 (20%) households were selected for the study by using a simple random method (balloting method). These selected respondents were then evaluated for their lung function – Forced Expiratory Volume at first second (FEV_1) and Forced Vital Capacity (FVC) using calibrated portable spirometer, To do this they were asked to put on loose light clothing with no shoes before measuring their weight (kg) and height (meters). Demonstration on how to use the spirometer was made by the researcher and then while respondent was in a comfortable sitting position spirometry testing was performed using a portable calibrated spirometer. Same calibrated spirometer was used throughout the study. Then the UCB Particle and Temperature Sensor (UCB-PATS) was used to collect 24 hour indoor mean particulate matter data following the manufacturer's procedure in manual (Household Environmental Monitor 2012). For each family, a pre-monitoring questionnaire (UCODEA/CEIHD/UC-Berkeley 2012) was administered. Socioeconomic variables like cost of firewood used were also collected using the questionnaire tool. Above data became the pre-intervention data.

During the intervention stage, each family was given the Envirofit improved stove to use for cooking. They were monitored weekly during unscheduled visits to ensure compliance with the use of Envirofit during cooking. Post-intervention i.e. after a period of about 6 months of using the stove, data collection procedure with the same UCB monitor and questionnaire were repeated. These data became the post-intervention data. Similar procedure as done during the pre-intervention stage was also used to obtain their lung functions. Results obtained during the post-intervention stage were then compared to those of the pre-intervention stage.

Data were analyzed using Statistical Package for Social Sciences (SPSS) version 13.0. The mean of the arithmetic means of indoor $PM_{2.5}$ before and after using cookstove were obtained and compared for any significant difference using the student t-test. For the lung function tests, Paired test was used to compare before and after using the improved stoves. Chi square tests were used to compare proportions of respondents that had obstructive conditions before and after using improved stoves. The amount spent on firewood when cooking with traditional stove versus when cooking with the improved stove were converted from local currency (Naira) to US dollar. Confidence interval used was 95% and p- values less than 0.05 were considered as statistically significant,

Results

A total of 89 households were selected for the study but only 81 households completed the study and hence were analyzed, giving a response rate of 91%. All the respondents were females. Sixty two (77%) had at least secondary education while 8 (10%) had no formal education. The age range was 21 to 81years and most (47%) were within the age group of 41 to 60 years (Table 1). Very few respondents (14.8%) were aware of any improved cookstove and even fewer people (9.9%) had seen one (Table 1).

Table 1 – Age, Education, main source of domestic cooking energy and awareness of clean cookstove

Variable	Frequency (%)
Age range (years) distribution	
• 20 – 40	21 (25.9)
• 41 – 60	47 (58.0)
• 61 – and above	13 (16.1)
Total	81 (100.0)
Formal Education completed	
• No formal	8 (10.0)
• Primary	24 (29.6)
• Secondary	30 (37.0)
• Post secondary	19 (23.4)
Total	81 (100.0)
Those who have heard of clean cookstoves	12 (14.8)
Sources of information on cookstoves	
• Neighbour	8 (9.9)
• Friend/Colleague	6 (7.4)
• Relative	3 (3.7)
• Other	1 (1.2)
Note: Some heard about cookstove from more than one source	
Those who have seen any improved cookstove before	8 (9.9)
Where did you see it?	
• Market	7 (8.6)
• Friend	2 (2.5)
• Neighbour	1 (1.2)
• Relation	2 (2.5)
• Colleague	2 (2.5)
• Television	2 (2.5)

There was significant reduction in the mean particulate matter concentration when the improved cookstove was used as the solution compared to when traditional stove was used (p =

0.02). Table 2 shows a 32.1% reduction in mean indoor $PM_{2.5}$ from firewood to cookstove. Plates 1a and 1b show pictures of $PM_{2.5}$ in one of the randomly selected homes (before and during the use of the improved cookstove).

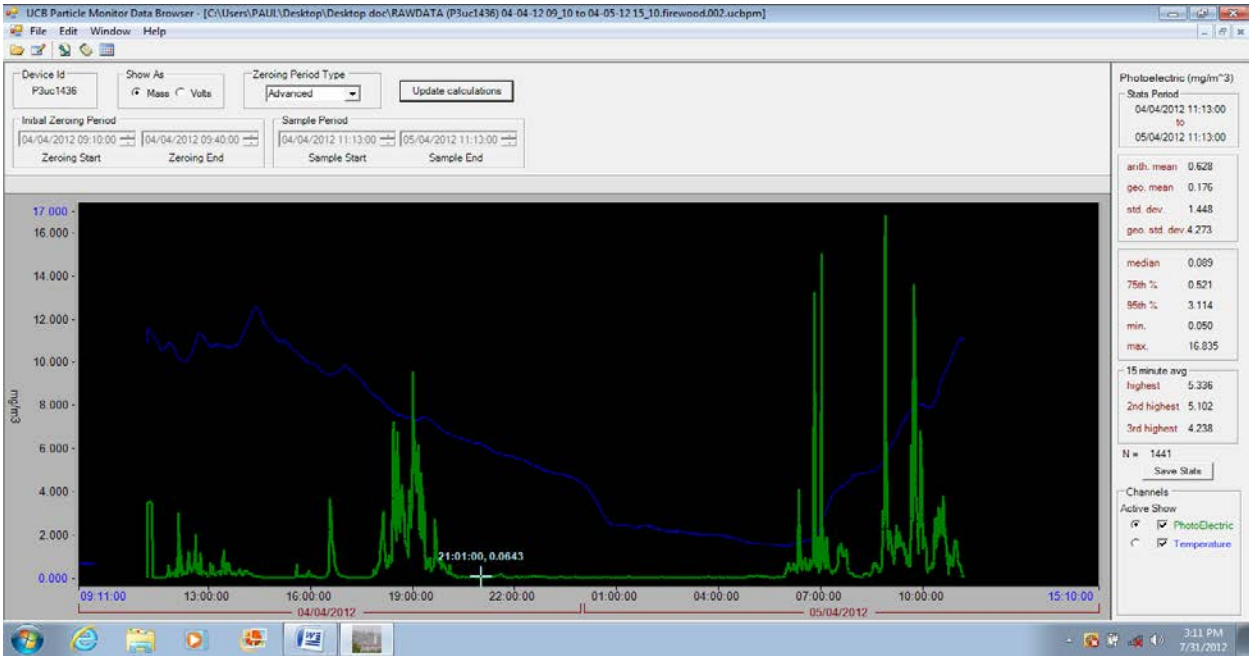
Table 2: Comparison of mean particulate matter (PM) before and during use of cookstove

Particulate Matter (PM)	Mean	N	Std. Deviation	Paired Differences	T test (P value)
				95% Confidence Interval of the difference	
Mean PM before cooking with cookstove	4.43	81	8.14	0.27 to 2.57	2.46 (0.02)*
Mean PM during cooking with cookstove	3.01	81	9.18		

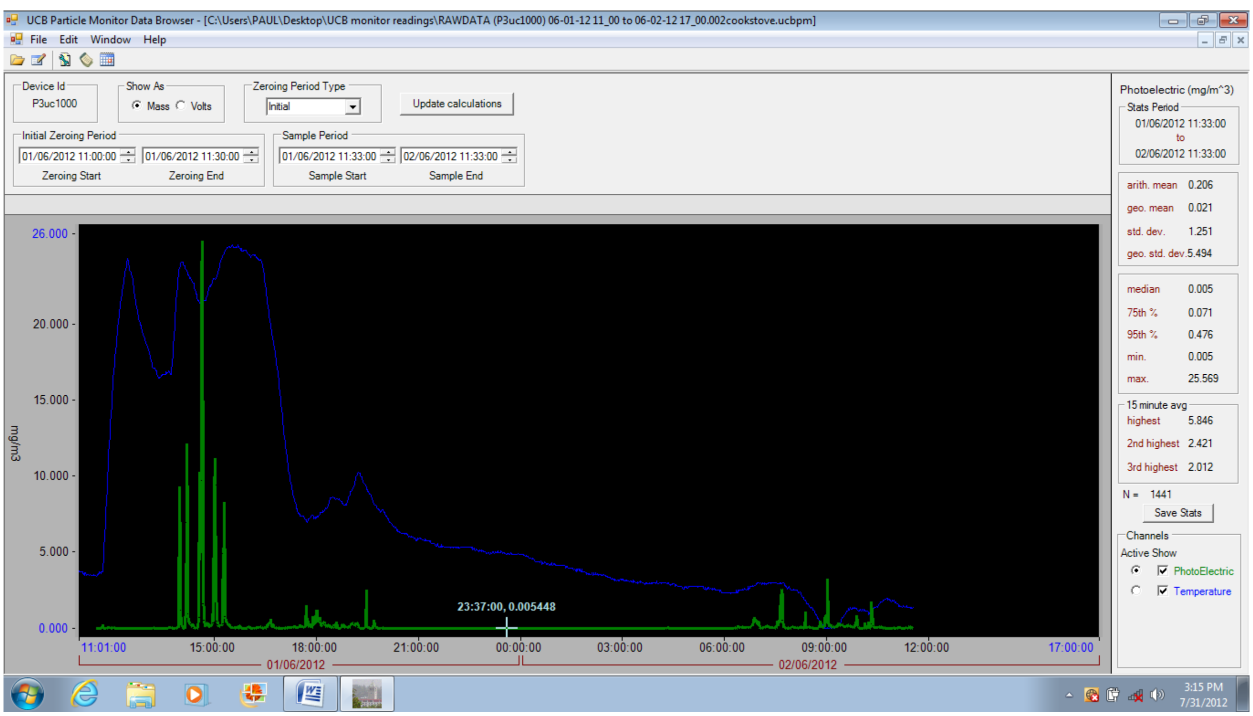
*Significant

The lung function (FEV_1 and FVC) of the 81 respondents whose kitchen were monitored for $PM_{2.5}$ improved and proportion of respondents who had obstructive lung conditions as obtained from FEV_1 / FVC% reduced while cooking with improved cookstoves.. These results were however not statistically significant (Table 3).

UCB1436.002firewood House 2 – Before



UCB1436.002cookstove House 2 - After



Plates 1a and 1b: Particulate matter before and after using Improved cook stove

- Green signifies - Particulate Matter in the air

TABLE 3: Lung function tests of respondents while using firewood and six months into using clean cookstove (before and after study)

Lung function tests	Cooking with firewood (N = 81)		After cooking with cookstove for 6 months (N = 81)		T test (P Value)
	Mean	SD	Mean	SD	
FEV_1	1.97	0.21	2.02	0.22	1.48 (0.141)
FVC	2.44	0.27	2.49	0.25	1.22 (0.223)
FEV_1/FVC (%)	80.7	2.5	81.1	2.8	0.96 (0.339)
	Respondents showing signs of obstruction based on FEV_1/FVC				
FEV_1/FVC value	Frequency	Percent	Frequency	Percent	χ^2 (P Value)
Normal	45	55.6	56	69.1	3.182 (0.074)
Obstruction	36	44.4	25	30.9	
Total	81	100.0	81	100.0	

Families spent three times on firewood when cooking with traditional tripod firewood stand than when cooking with improved cookstoves (Table 4).

Table 4: Amount spent weekly on firewood compared to other fuel sources

	Weekly average spent on cooking item			
Cooking item	No. of households using item	Weekly Range (US dollars)	Weekly average (US dollars)	
			Amount (US dollars)	Standard deviation
*Kerosene	422	4.69 – 10.00	5.63	63.68
*Gas cooker	56	5.63 – 14.38	10.94	127.09
*Electricity	Cannot be estimated			
*Charcoal	2	8.75 – 10.04	9.39	54.77
Firewood	**81**	**4.31 – 13.13**	**10.42**	**83.12**
Cookstove	**81**	**2.19 – 4.47**	**3.60**	**28.88**

*The estimates obtained from households using other fuel sources

Discussion

Despite well documented evidence of the harmful effects of the use of solid fuels on both the environment (deforestation, soil erosion, flooding, global warming, declining agricultural productivity, etc) and health of especially mothers and children (pneumonia, lung cancer, chronic obstructive lung disease, heart disease, etc), present study observed that many households studied still use biomass as their main source of fuel for cooking. This is similar to global estimates of about 50% that use biomass (Staton and Harding 2012). Use of biomass differs from country to country and even within the same country from one region/community to another. In Nigeria 70% use solid fuels and even most of these use open fire/stove without chimney or exhaust hood (Desalu et al 2012). This use is greater in rural Nigerian communities where in a particular community up to 84% of the dwellers used biomass as source of fuel (Desalu et al. 2012) interestingly, even the educated are not isolated from the exposure to pollution from use of biomass as fuel. In the present study, about 60% of those interviewed had at least secondary education and many of them use solid fuels. Hence, the use of this source of fuel may not be from illiteracy alone but also from other factors like income, lack of knowledge of health consciousness of indoor air pollution and low awareness of existing alternative improved cookstoves (Duflo et al 2008; Mobarak et al. 2012).

Awareness of the availability of improved cookstoves among the respondents in the present study was very poor and most had not even seen one before. A previous study showed that the level of education, distance of household from urban areas, whether or not the household owns the dwelling unit, and whether or not the dwelling unit is traditional or modern type are all significant factors in determining the probability of switching from firewood to other fuel options (Njong and Johannes 2011). Such low demand may affect sustainability of any programme targeted at use of improved cookstoves. To address this, a list with indicators for assessing sustainability was developed (Brinkmann et al. 2012). These are divided into two categories: Sustainability criteria which assess whether the changes induced by the project are sustainable or not; and Sustainability factors, which influence the probability of achieving sustainable results (Brinkmann et al. 2012). Sustainability criteria are measured by the following: penetration rate, usage rate, maintenance rate and replacement rate (Brinkmann et al. 2012). Present study shows penetration rate and usage rates for Envirofit to be very low just like in the study by the Global Alliance for clean cookstoves in other parts of the country (A report by Global Alliance for clean cookstoves on Nigeria 2014).

Reduction of release of particulate matter and other poisonous gases is of critical importance to health and environment. Several studies on reducing indoor pollution resulted in development of improved cookstoves (Onah et al 2005; Bhattacharya et al 2002). Some of these studies resulted in use of reduced quantities of firewood (e.g. Envirofit), charcoal (Toyola energy limited), kerosene and alcohol. All of these showed significant reduction in indoor air pollution (Onah et al 2005; Bhattacharya et al 2002). In the present study, there was significant reduction in indoor $PM_{2.5}$ released while cooking with improved cookstove than when cooking with traditional stoves. Also using the improved cookstove resulted in 32.1% reduction in mean indoor $PM_{2.5}$ compared to when traditional tripod stand firewood was used. This observed reduction, though significant is less than values obtained in another study where Envirofit was observed to reduce emissions by as much as 80% (Jetter et al 2012). This difference may be due to different study settings or environment e.g. ventilation in cooking environment. In several other studies using different types of improved cookstove under laboratory settings, indoor particulate matters have been observed to be reduced by as much as 50% , 92% and 48%

(Global Alliance for clean cookstoves 2003; Donelly 2013; Ezzati et al 2000) respectively. Indeed other studies have also compared various types of improved cookstoves (Ezzati et al 2000; CEIHD/Gaia Association 2007).

The present study recorded improved lung function and reduced proportion of respondents with obstructive lung condition 6 months after using the improved cookstove. These findings were however not statistically significant. The reason may be due to the short time before evaluation. Changes in lung parameters may take longer than 6 months intervention to show significant changes on spirometry. There is an established relationship between presence of particulate matter and lung pathologies like obstructive conditions (Karakatsani et al 2012). Studies have also shown that both outdoor particulate matter (Neuberger et al 2004; Ko et al 2007; Zanobetti et al 2000; Medina-Ramon et al 2006) and indoor particulate matter (Karakatsani et al 2012; Smith et al 2000; Bruce et al 2000; Ezzati and Kammen 2001) are associated with various lung pathologies including obstructive conditions. Similarly the finer particulates [$PM_{2.5}$] and coarse particles have been shown to be associated with obstructive lung conditions (Karakatsani et al 2012; Neuberger et al 2004).

Although the present study was not done under controlled environmental conditions, an important observation from the p study is that less quantity of firewood was used for cooking and hence less amount was spent on firewood. This finding is supported by other studies which indicate that improved stoves could use 60% less fuel when compared to traditional stoves.

Strength of study

This study is one of the few that relates the effect of particulate matter on the lung function. It also highlights the economic effect of using improved cookstoves compared to traditional stoves.

Limitations of study

It was difficult to ascertain the various types and nature (dry or wet) of the firewood used to cook at various times. To correct for this, they were informed to use same type of wood before and during use of the improved stove. Also, it is a before and after study and so likely to have other confounders. For instance seasonality and time-varying determinants of exposure could confound the results.

Conclusion and Recommendation

Present study has established the low awareness of improved cookstove among the respondents. There is also significant reduction in the mean indoor particulate matter by using the improved stove and this consequently resulted in improved lung function parameters e.g. FVC1 and FVC. There is also less money spent on firewood by using the stove. It is therefore recommended that greater awareness and availability of the improved cookstove be made for use at homes in communities that cook with firewood.

Conflict of Interests: There are no conflicts of interest.

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