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Health Impact of Locally-Produced, Improved Ceramic Cookstoves on Children in rural Western Kenya

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An abstract of
A thesis submitted to the Faculty of the
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Abstract

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Pneumonia is the leading cause of death of children under 5 years old. Indoor air pollution (IAP) is a major risk factor for pneumonia. Unprocessed biomass fuels, commonly used in households in developing countries, generate high levels of IAP. Improved cookstoves reduce IAP in comparison to traditional indoor open fires. In rural Kenya, a non-governmental organization sold ~2,500 inexpensive (US$3) ceramic cookstoves (jikos) from 2008-2010. In one study, jikos reduced smoke in the home, cook times, fuel use, and airborne particles ≤2.5 μm in diameter by 13%. We conducted a longitudinal observational study on the health impact of jikos on children under 3 years old in 20 villages. We enrolled 200 households with children <24 months old and fieldworkers conducted 25 biweekly household visits. The child's caretaker reported their primary stove use in the past week. Fieldworkers observed children for signs of pneumonia following WHO IMCI guidelines. Reported stove use during 3,951 biweekly home visits over a year, included 3-stone firepit (81.8%), jiko (15.7%), both (2.3%), and other (0.2%).In 99.9% of visits, respondents reported burning unprocessed biomass fuel. A lower percentage of children in jiko-using households had cough (1.5% vs. 2.9%, rate ratio [RR], 0.5, 95%CI: 0.3, 1.2), pneumonia (1.0% vs. 1.7%, RR 0.7, 95%CI: 0.3, 1.8) and severe pneumonia (0.3% vs. 0.5%, RR 0.8, 95%CI 0.2, 3.1). Cell phone ownership, a proxy for socioeconomic status among respondents, was associated with jiko use (p<0.01). Cell phone ownership was also independently associated (p<0.03) with a lower rate of severe pneumonia and cough and there was a trend towards association of a decreased rate of pneumonia (p=0.053). Although jiko use was not associated with a significant reduction in the rate of respiratory illness when compared to 3-stone firepit use, analysis was limited by insufficient statistical power. Since the data suggested a beneficial effect of jiko use, further research on the health impact of, and equity of access to, improved cookstoves is warranted. Interventions to prevent pneumonia should utilize an integrated approach including reducing IAP, as well as addressing risk factors such as low birthweight, crowding, and immunization and nutritional status.

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INTRODUCTION

Pneumonia is the leading cause of death of children under 5 years old worldwide. It is the cause of 1.6 million child deaths each year, and approximately 70% occur in Southeast Asia and sub-Saharan Africa (1, 2). Of the 156 million episodes of pneumonia that occur worldwide each year, 151 million occur in developing countries (2).

Indoor air pollution (IAP) is a major risk factor for pneumonia (2). Cooking indoors with open fires or inefficient traditional stoves is common in developing countries and generates high levels of IAP (3). Women who prepare food and their young children often receive the greatest exposures to IAP and are at highest risk for adverse health effects (4). Young children who are exposed to indoor air pollution have 1.8 times the risk of acquiring pneumonia (5). In 2000, it was estimated that 910,000 deaths from acute lower respiratory infections (ALRI) were attributed to IAP among children under 5 years old (6).

To address the problem of indoor air pollution, an effort is underway to develop improved cookstoves to reduce emissions of particulate matter. The Global Alliance for Clean Cookstoves, a public-private partnership, was formed to encourage the adoption of 100 million clean cookstoves by 2020 despite limited evidence on the health benefit of cookstoves(7, 8). To date, no studies have evaluated the health impact of improved cookstoves that do not vent smoke outside of the home. Cookstoves that do not vent smoke are less expensive and may be more easily scalable worldwide. Furthermore, venting smoke outside the home does not necessarily eliminate particulate matter emissions from the environment (8).

From 2010-2011, a one-year, longitudinal observational study was conducted on the impact of improved cookstoves that do not vent smoke outside the home on respiratory illness in children in rural villages in Nyando District, Nyanza Province, Kenya. In this region, unprocessed biomass fuels are used by nearly all households for cooking [Silk, unpublished]. Other risk factors for respiratory illness such as malnutrition, low birthweight, lack of measles vaccination, and household crowding are also common. We compared the rate of respiratory illness in children living in households in which the primary caretaker reported using an improved cookstove to households with reported use of a traditional indoor 3-stone firepit.

The study hypothesis was that the use of an improved cookstove lowers the rate of respiratory illness in children less than 3 years old compared to households that use a traditional 3-stone open firepit.

BACKGROUND

Approximately 3 billion households burn unprocessed biomass fuels for heating and cooking, generating high levels of indoor air pollution(6). Unprocessed biomass fuels include any combustible plant or animal material including wood, charcoal, dung and crop residues. Between 50% and 95% of households in developing countries use biomass fuels for domestic heating and cooking (6). The use of these fuels is responsible for substantial carbon emissions and contributes to deforestation (9). Burning unprocessed biomass fuels indoors results in smoke and particulate matter emissions between 10 and 100 times recommended levels (10).

Particulate matter (PM) is defined as airborne solid or liquid droplets. Particles ≤10 μm in size are associated with adverse health effects, and fine particles ≤2.5 μm (PM2.5) can penetrate deeper into the lungs and are potentially more harmful (11). Inhaled PM suppresses the immune system, inflames airways, causes oxidative stress, and provides a surface from which bacteria are able to attach to airways, increasing the risk of pneumonia (11-14). The risk of pneumonia increases with increasing exposure time and particulate matter concentration (10). PM exposure also increases the risk of asthma, acute otitis media, and upper respiratory infections (15, 16).

Other risk factors for pneumonia that are common in regions with impoverished populations and prevalent exposure to IAP include malnutrition, low birthweight, non-exclusive breastfeeding during the first 4 months of life, lack of measles vaccination, and crowding (2, 17).

One study has evaluated the impact of improved cookstoves use over time on respiratory infections in young children. In this field trial, improved cookstoves ventilated emissions outside the home. Physicians diagnosed cases of pneumonia using physical exam (8). A lower percentage of children living in households with an improved cookstove than in households using a traditional open firepit had an acute lower respiratory infection (ALRI, main outcome) (Rate Ratio [RR] 0.78, 95%CI: 0.59, 1.06) and physician-diagnosed ALRI with hypoxemia (O_2

Saturation ≤87%) (RR 0.67, 95%CI: 0.45, 0.98). Investigators also found that the risk of physician diagnosed childhood ALRI increased with increasing exposure to indoor air pollution. Measurements taken over 48 hours showed that children in homes with improved cookstoves had a 50% decrease in exposure to indoor air pollution (8). It was thought that the main outcome was not reached because of insufficient particulate matter reduction and insufficient power. The study suggested that at lower levels of exposure to indoor air pollution, the risk curve for ALRI was steeper than at higher levels of exposure (8); a decrease of indoor air pollution by 50% with a baseline level of exposure at 2.2 ppm CO does not decrease the risk of respiratory illness as much as if the baseline exposure was closer to 1 ppm. In the study, carbon monoxide (CO) levels in the home correlate well with PM2.5 levels generated from household sources (4). A CO level of 1.1 ppm is approximately equivalent to a PM2.5 level of 190µg/m^3 which is nearly eight times WHO recommended levels(18).

This study was conducted in a rural, Luo community of roughly 300,000 people located in Nyanza Province, Nyando District, Kenya, approximately 30 km east of the provincial capital of Kisumu. People living in this region were predominantly subsistence farmers. A recent survey estimated the average household size was 4.5 persons and 16.4% of the population was under 5 years of age (19).

According to the 2008-2009 Demographic Health Survey (DHS) for Kenya, the mortality rate of children <5 years old was 149 per 1,000 live births in Nyanza Province, the highest in all of Kenya (20). A 2002 study in western Kenya reported that 16.5% of deaths of children under 5 years old were due to pneumonia and that it was the fourth most common cause of death for children under 5 years old(21). The DHS reported that in the 2 weeks preceding the survey, 7.9% of children under 5 years old had symptoms of acute respiratory infection. Respiratory illness was responsible for 25.7% of sick visits, the second most common cause of these visits (20, 21). In 2007, approximately 20% of preschool aged children had malaria parasitemia, and 28% of Nyando District preschool-aged children were stunted (22).

In a prior community wide survey, 99.9% of households in Nyando District reported using a 3-stone firepit for cooking and >95% of households burned unprocessed biomass for fuel. Residents in these communities desired reduced smoke in their homes and were concerned about adverse health effects related to 3-stone firepit use including breathing smoke (80%), burns (37%), and respiratory infections (11%) [Silk, unpublished].

To address this issue, a local non-governmental organization (NGO), the Safe Water and AIDS Project (SWAP), encouraged the adoption of ceramic cookstoves (upesi jiko, Swahili for quick stove) in homes in Nyando District (Figure 1). Upesi jikos (jikos) were made locally by a women's pottery group and consisted of a ceramic liner made from clay and built into the kitchen area of a dwelling [Silk, unpublished]. The jiko was selected because of its durability, availability and affordability [Kenya Shillings (KSh) 150-300 or US$2-3] within the population. Jikos burn unprocessed biomass fuel and do not ventilate smoke outside. Local women's HIV support groups organized by SWAP sold jikos to community members as an income generating activity. In total, 2,500 stoves were sold between 2008-2010.

A CDC evaluation of the efficiency of jikos found that jiko use noticeably reduced visible smoke in the homes, fuel use, and cook times [Loo, unpublished]. PM2.5 was reduced by 13%, from 125 $\mu g/m^3$ to 109 $\mu g/m^3$ in households that used a jiko. Evidence on PM2.5 reductions necessary to achieve health benefits is limited, but it is believed that levels should be reduced to WHO recommended levels (25 $\mu g/m^3$) to decrease mortality due to exposure to indoor air pollution (8, 23).

From April 2010-April 2011, we conducted a study in a random sample of 20 villages in Nyando District, Kenya to assess the health impact of a household water filter on children less than 3 years of age. During that study, we collected data on the type of cookstove used and respiratory illness in the same cohort of children. Our objectives were to determine the use of jikos in study households, assess the use of unprocessed biomass fuels, and compare the rate of cough, pneumonia, and severe pneumonia in children under 3 years of age living in households using a jiko to households cooking with a 3-stone firepit.

METHODS

Null Hypothesis:

There is no difference in the rate of respiratory illness (cough, pneumonia, or severe pneumonia) in children less than 3 years old in households that report 3-stone firepit use compared to households that report jiko use.

Study design:

From April 2010 to April 2011, we conducted a longitudinal observational study in a cohort of families in 20 randomly selected villages to examine the health impact of upesi jiko stoves. We completed enrollment and collected baseline data between September 2009 and February 2010. The year-long observational period began in April 2010, and households were visited biweekly. During 25 biweekly home visits, fieldworkers collected data on fuel use, jiko use, and episodes of cough, pneumonia, and severe pneumonia in children less than 3 years old.

Study Population:

Twenty villages in Nyando District, Kenya were randomly selected from the 60 villages in the Nyando Integrated Child Health Project(NICHE) (22). All households in the study villages with a child <24 months old were enrolled.

Sample Size:

The water filter field trial was designed to measure the effect of household water treatment on diarrheal disease. Consequently, power calculations were not performed to measure the effect of stove use on respiratory illness in children.

Baseline data collection:

Between September 2009 and February 2010 households were enrolled, and baseline data were collected on socioeconomic and demographic characteristics, sanitation facilities, and hygiene practices.

Biweekly home visits:

Fieldworkers visited households every 2 weeks beginning in April 2010. Fieldworkers conducted interviews with the child's primary caretaker about the household's primary stove and fuel use in the past week, the presence of cough in children, and diagnosed pneumonia using the World Health Organization's Integrated Management of Childhood Illness (IMCI) algorithm, which has a sensitivity of 97% and a specificity of 49% to diagnose pneumonia in malaria-endemic areas in Kenya (24).

Case Definitions:

For this evaluation, we asked the primary caretaker about cough in the child during the preceding 24 hours. We defined pneumonia as cough plus rapid respiratory rate, measured over 60 seconds and adjusted for age (24). We defined severe pneumonia as cough plus observed chest wall indrawing or one or more of the following danger signs: convulsions, lethargy, unconsciousness, or inability to eat or drink.

Data analysis:

Data were recorded in Personal Data Assistants. The data were uploaded into Microsoft Access databases and transferred to SAS (version 9.2) for statistical analysis. Households in which fewer than 19 of 25 home visits were completed (<75% of visits) were excluded from analysis. To compare baseline characteristics among households, we compared households that ever reported using a jiko to those that only reported using a 3-stone firepit. Crude cough, pneumonia, and severe pneumonia rate ratios were calculated by dividing the percentage of visits in which episodes of cough, pneumonia, or severe pneumonia were found in households reporting jiko use by the percentage of visits where respiratory illness was found in households reporting 3-stone firepit use.

A multivariable model was developed using general estimating equations (PROC GENMOD) to account for repeated measures using an autoregressive correlation structure. Rate ratios and 95% confidence intervals were estimated. We collected data on several categories of covariables at baseline, including household assets (land ownership, number of rooms, electricity, cell phone, radio, TV, bicycle, roof type and floor type), demographic characteristics (maternal education, child age, child sex), and hygiene and sanitation indicators (presence of soap in the home, presence of a latrine, maternal ability to demonstrate proper handwashing).

To control for potential confounding by SES, we compared household asset ownership between households that ever reported jiko use to households that only used a 3-stone firepit. We included any covariates in the multivariable model that were significantly associated ($\alpha=0.05$) with stove type. We used a forward stepwise method to evaluate all other possible covariates to see if they changed the association between the exposure and the outcome by more than 15%. These variables were also included in the final multivariable model.

We also used a propensity score analysis to estimate the effect of stove use on respiratory illness in children. Using stove type as the outcome, and all measured covariables (household assets, demographic characteristics, and hygiene and sanitation indicators) as predictors, we developed a multivariable logistic model to find the probability that each household was exposed to a jiko. We then divided the households into quintiles of probability of jiko exposure and measured the health impact within these quintiles. This permitted a comparison of the effect of stove type between households that had similar socioeconomic, demographic, and hygiene and sanitation characteristics, thereby reducing bias from confounding.

It is possible that children that were consistently exposed to less indoor air pollution over time due to consistent cookstove use may have received a greater benefit than children in households that intermittently used the cookstove. To explore this possibility, we compared risk of respiratory illness in households that reported using a jiko in >80% of visits to households that reported exclusively using a 3-stone firepit.

Ethics:

The protocol was approved by institutional review boards at the Kenya Medical Research Institute (protocol 1458) and the Centers for Disease Control and Prevention in Atlanta, GA, USA (protocol 5039). Emory University IRB deferred to CDC IRB for approval of this protocol. We obtained informed consent from all participating households and removed personal identifiers from databases at the end of the study.

RESULTS

We enrolled 200 households, of which 168 (84%) completed >75% of biweekly visits. At baseline, the mean respondent age was 26.9 years, 99% were female, and 65% had completed primary education (Table 1). Mean child age was 5.7 months; 53% were male. At baseline, there were no differences in child health status, maternal age, or educational level between households that reported ever using a jiko to households that reported exclusively using a 3-stone firepit.

Of 3,951 total biweekly home visits made over the course of the study, exclusive 3-stone firepit use was reported in 3,232 (81.8%), exclusive jiko use in 619 (15.7%), use of both a 3-stone firepit and jiko in 94 (2.3%) and other stove use in 6 (0.2%). Of the 168 households, 166 households used only a jiko or a 3-stone firepit, 2 households used an alternative stove at some point during the study. The percentage of households reporting exclusive jiko use was similar (12.1%-19.3%) throughout the course of the study (Figure 2). Jiko use was reported during >80% of visits at 23 (14%) households; these households accounted for 501 (81%) jiko visits. Respondents who reported ever using a jiko were more likely than those who reported 3-stone firepit use to live in households with a cell phone (89% vs. 59%, $p<0.01$), an iron roof (72% vs. 50%, $p<0.01$), a bicycle (75% vs. 57%, $p=0.02$),and access to electricity (5% vs. 0%, $p=0.048$). Respondents who had a cell phone were more likely than those without a cell phone to live in a household with an iron roof (67% vs. 40%, $p<0.01$), have a bicycle (76% vs. 36%, $p<0.01$), have more than 1 room in their house (36% vs. 20%, $p<0.01$), have a cement floor (4% vs. 2%, $p<0.01$), a radio (90% vs. 75%, $p<0.01$), have a TV (18% vs. 6%, $p<0.01$), and own their land (70% vs. 60%, $p<0.01$).

Caretakers reported burning unprocessed biomass fuel for cooking in the previous week in 99.9% of biweekly home visits. Caretakers reported using wood only (84.3% of visits); crop waste and wood (11.3% of visits); charcoal and wood (2.5% of visits); charcoal only (1.3% of visits); and crop waste only (0.3% of visits).

Over the course of the study in the 168 children included in the analysis, 106 (63%) had no reported episodes of cough, 36 (21%) had 1 episode, and 26 (15%) had multiple episodes. Of 168 children, 123 (73%) had no episodes of pneumonia, 35 (21%) had 1 episode, and 10 (6%) had multiple episodes; 150 (89%) had no episodes of severe pneumonia, 16 (10%) had 1, and 2 (1%) had 2 episodes.

In bivariate analysis, a lower, but not statistically significant, percentage of children in jiko using than in 3-stone firepit using households had cough (1.5% vs. 2.9%, RR 0.5, 95%CI: 0.2, 1.0), pneumonia (1.0% vs. 1.7%, RR 0.6, 95%CI: 0.2, 1.4), and severe pneumonia (0.3% vs. 0.5%, RR 0.6, 95%CI: 0.2, 2.3) (Table 2). A lower percentage of children in consistent jiko-using than in 3-stone firepit using households had pneumonia (0.7% vs. 2.1%, RR 0.4, 95%CI: 0.1, 0.9) (Table 3). Consistent users also had a lower, but not statistically significant percentage, of children with cough (1.5% vs. 3.4%, RR 0.4, 95%CI: 0.2, 1.2), and severe pneumonia (0.4% vs. 0.7%, RR 0.6, 95%CI: 0.1, 2.4) (Table 3). A lower percentage of children in households with a cell phone had cough (2.1% vs. 3.9%, RR 0.5, 95%CI: 0.3, 0.9), pneumonia (1.2% vs. 2.5%, RR 0.5, 95%CI: 0.3, 0.97), and severe pneumonia (0.3% vs. 0.9%, RR 0.4, 95%CI: 0.1, 0.9) (Table 4). Household TV possession was associated with a lower rate of cough (1.0% vs. 2.9%, RR 0.4, 95%CI: 0.1, 0.9) and household radio possession was associated with a lower rate of severe pneumonia (0.3% vs. 1.6%, RR 0.2, 95%CI: 0.1, 0.5).

In a multivariable model adjusting for household assets, demographic and hygiene and sanitation indicators and accounting for repeated measures, children in jiko-using households had less cough (RR 0.5, 95%CI 0.3, 1.2), pneumonia (RR 0.7, 95%CI: 0.3, 1.8), and severe pneumonia (RR 0.8, 95%CI: 0.2, 3.1), however, these associations were not statistically significant (Table 2). In a multivariable model adjusting for household assets, demographic, and hygiene and sanitation indicators and accounting for repeated measures, children in consistent jiko-using households had less cough (RR 0.5, 95%CI 0.2, 1.2), pneumonia (RR 0.4, 95%CI: 0.2, 1.2), and severe pneumonia (RR 0.8, 95%CI: 0.2, 3.2) than 3-stone only users (Table 3). However, these associations were not statistically significant.

A multivariable model accounting for repeated measures and adjusting for stove use, demographic, hygiene, and sanitation indicators demonstrated that cell phone and TV ownership were independently associated with decreased cough. Radio ownership showed a trend towards an independent association (p=0.07). Cell phone and radio ownership were independently associated with decreased severe pneumonia (Table 4). Cell phone ownership showed a trend towards being independently associated with decreased pneumonia (p=0.053). No associations were found between respiratory illness and maternal education, observed soap in the home, presence of latrine, and the primary caretaker's ability to demonstrate proper handwashing.

DISCUSSION

Results of this longitudinal, observational study suggest that children in households using upesi jikos experienced approximately half the rates of reported cough, fieldworker-diagnosed pneumonia, or severe pneumonia than children exposed to traditional 3-stone open firepits. While none of these findings were significant in our study, the effect sizes are similar to those found which were found in the RESPIRE trial in Guatemala (8).

There are several possible explanations for our lack of significance. First, jikos may not have lowered particulate emissions sufficiently to decrease disease rates. As mentioned above, prior research in this population found a 48-hour average reduction of PM2.5 of 13% in households with a jiko (28% reduction in ppm CO) [Loo, personal communication] (25). Households that were using a jiko may have been also using a 3-stone firepit, a practice that was observed anecdotally, thereby decreasing the potential benefit of jiko use. The RESPIRE trial was designed to detect a reduction in pneumonia assuming a 50% reduction of carbon monoxide exposure, which is approximately equivalent to a 40% reduction in PM2.5. The mean PM2.5 levels achieved by jiko households in our study were about 4 times greater than WHO recommended levels (18). PM2.5 levels likely need to be reduced to levels closer to the WHO recommended level to prevent mortality associated with indoor air pollution.

A second challenge was the fact that this was an observational study and households were not randomly assigned stoves. Households that were observed to have cell phones were significantly more likely to have a jiko, and children in those households were less likely to experience respiratory illness. We adjusted for this confounding using a multivariable modeling and a propensity score analysis. A propensity score analysis helps reduce bias in observational studies by adjusting for differences in study subjects. This method has been recommended by others for use in observational studies evaluating the health impact of improved cookstoves(26). These two methods to adjust for confounding resulted in similar effect sizes. However, the adjustments for confounding may be imperfect as household assets are proxy measures for SES.

There also may be unknown risk factors for respiratory illness that are unbalanced between cookstove users and 3-stone firepit users. The presence of other respiratory illness risk factors including malnutrition, lack of breastfeeding status, lack of measles vaccination, household crowding, low birthweight, presence of malaria infection, and HIV status, were not collected.

An important finding from this study was that household assets (e.g. cell phone, radio, and TV) were independently associated with less respiratory illness. The effect sizes for the relationship between respiratory health and these proxy measures for SES were larger in comparison to cookstove effect sizes. Future public health interventions to combat pneumonia in children should address risk factors for pneumonia potentially related to socioeconomic status such as malnutrition, crowding, measles vaccination, and low birthweight as well as indoor air pollution, because a cookstove intervention alone will not reduce the high burden of pneumonia in developing countries.

Third, the sample of children in this study was insufficient to provide adequate statistical power to detect differences between jiko users and 3-stone firepit users. Authors of the RESPIRE trial suggested that future studies have a sample size of 1500, assuming the effect size of improved cookstoves was similar to what they obtained (27). This study's sample size was only 168 and there were lower rates of disease in this population than in the RESPIRE trial. In this study, pneumonia was detected in 1.4% of all visits, compared to 2.3% of visits in the RESPIRE trial (8). The lower number of cases and small sample size decreased the likelihood of finding a significant association between stove use and respiratory illness.

Although jiko use was not associated with a significant decrease in rate of respiratory illness, one desirable feature of jiko use observed (Person, in press; Loo, unpublished data) was a noticeable reduction in visible smoke in the home. In addition, jikos burned fuel more efficiently and cooked food faster than a 3-stone firepit. This potentially would have decreased exposure to smoke in the home [Loo, unpublished data]. Breathing wood smoke is a risk factor for pneumonia, and chemicals in wood smoke provoke inflammatory responses in the lungs, irritate airways and suppress the immune system (12). The potential of jikos to reduce exposure to airway irritants in the home, even in the absence of a meaningful effect on PM2.5, may have had a beneficial impact on respiratory symptoms.

Another possible explanation for lower respiratory illness rates among children in the jiko-using group is suggested by the shape of the dose response curve for indoor air pollution and pneumonia found in the RESPIRE trial. The study suggested that at lower levels of exposure to indoor air pollution, the risk curve for ALRI was steeper than at higher levels of exposure (8). The baseline level of exposure to PM2.5 in the RESPIRE trial was approximately 2.5 times higher than in this study (320 $\mu g/m^3$ vs. 125$\mu g/m^3$respectively) (25). Data from the RESPIRE trial suggest that a smaller decrease in PM2.5 levels from the baseline level in our study may have the potential to have a similar effect on respiratory illness as the stoves in RESPIRE because of the shape of the risk curve for ALRI and indoor air pollution.

When examining the effect size, the benefit of jiko use may be greater in households that report consistent use as seen by comparing the effect sizes from (Table 2 vs. Table 3). Prior studies have suggested that duration of exposure is an important risk determinant, but whether consistent users receive a greater benefit than inconsistent users is unknown (10). This question could not be answered in this study due to small sample sizes butis likely an important question that should be addressed by future studies.

Our study demonstrated several findings that may be relevant for efforts to increase use of improved cookstoves. First, according to Safe Water and AIDS Project (www.swapkenya.org), over 2,500 jikos were sold in 3 years, suggesting that demand for jikos was robust (Sadumah, unpublished). Others' experience suggests that reasons besides health benefits drive demand for health products and influence the consistency of their use (28). In the case of jikos, convenience of use, improved surface for food preparation, reduced visible smoke in the home, household cleanliness (e.g., decreased soot on the walls), and need for less fuel [Silk, unpublished data, Loo, unpublished data] were cited as benefits of jiko use. As higher efficiency stoves are developed, it will be important to assure that the design is acceptable to the users for many non-health reasons to increase the likelihood of adoption and regular use.

Second, although jikos were available and promoted in this region and the population was concerned about indoor smoke and health effects from indoor air pollution, most households (63%) in this study did not buy a jiko, likely as a result of economic considerations. Households lacking certain assets, proxy measures for SES, were less likely to report using a jiko despite the relatively low cost (3 USD). In this case, a market-based distribution mechanism, such as the plan of the Global Alliance for Clean Cookstoves, may have limited success in reaching the poorest households where children are at highest risk(29). This concern is amplified by the unsuccessful commercial approaches to disseminating insecticide treated bed nets to poor populations (17, 29). Instead, access to insecticide treated bednets in resource-poor settings has been dramatically increased in recent years through free distribution or highly subsidized pricing. This experience should be useful in informing future plans to disseminate improved cookstoves(29).

This study had several important limitations. First, because this was an observational study, jikos were not randomly assigned to households. Second, data were collected in the context of another study, and as a result the sample size for this evaluation was not designed to detect the health impact of the jiko. Consequently, the study was underpowered for assessing the impact of jikos on respiratory illness. Third, data on important potential risk factors for respiratory illness, including malnutrition, lack of breastfeeding, lack of measles vaccination, household crowding, low birthweight, presence of malaria infection, and HIV status were not collected. Fourth, fieldworkers diagnosed cases of pneumonia using IMCI guidelines. Fieldworkers were not trained clinicians and diagnostic tests such as chest X-ray and pulse oximetry were not used, which adversely impacted the accuracy of diagnosis. Fifth, we did not measure individual particulate matter exposures in children over time so the extent to which childhood exposures were reduced in households using a jiko was unknown. Finally, the villages in this study were selected in one district of Nyanza Province, so the study population may not be representative of either Nyanza Province or Kenya.

CONCLUSION

Pneumonia is the leading cause of death of children worldwide. Exposure to indoor air pollution from burning unprocessed biomass fuels is common worldwide and is a major risk factor for pneumonia. However, an intervention that reduces indoor air pollution, is acceptable to users, prevents adverse health effects, and can be sustainably scaled up worldwide has not been developed. Data linking particulate matter exposure reductions to health outcomes are limited and it is unclear what level of reduction of indoor air pollution are necessary to prevent most adverse health outcomes. It is unlikely that there will be one technology that reduces indoor air pollution that will work well in every setting in the developing world. Consequently, there is a critical need to focus research efforts to develop a variety of improved cookstoves, test them in the field, and demonstrate their health impact. Interventions that decrease indoor air pollution should also be combined with interventions that address other major risk factors for pneumonia including those related to SES to achieve the greatest health benefits.

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Table 1: Baseline Demographic Characteristics of Caretakers and Enrolled Children; Household Assets; and Water Handling, Sanitation, and Hygiene Practices, Among Users of UpesiJiko Stoves and 3-Stone Firepits, Nyando District, Kenya Who Completed >75% of Biweekly Visits

Characteristics	Any Reported Jiko Use	3-Stone Firepit Only (100% use)	P value
% of households (N)	36% (61)	63% (105)	-
Primary Caretaker			
Female (%)	100	98	0.53
Mean Age (yrs)	27	27	0.95
Completed Primary School (%)	73	62	0.13
Child			
Male (%)	54	52	0.83
Mean Age (mo.)	5.4	5.8	0.53
Cough in last 24 hours (%)	44	33	0.16
Fever in last 24 hours (%)	38	36	0.85
Household Assets			
Electricity (%)	5	0	0.048
Cell phone (%)	89	59	<0.01
Bicycle (%)	75	57	0.02
Mean Number of Rooms (n)	1.36	1.32	0.68
Radio (%)	87	84	0.59
TV (%)	16	11	0.36
Refrigerator (%)	2	0	0.37
Motorcycle (%)	0	0	1
Car (%)	2	0	0.37
Own Land (%)	67	66	0.84
Iron Roof (%)	72	50	<0.01
Mud Floor (%)	95	98	0.36
Mud Wall (%)	92	98	0.13
Water, Hygiene and Sanitation			
Water Storage Container (%)	100	99	1
Soap Observed (%)	92	87	0.37
Primary Caretaker Demonstrated Proper Handwashing(%)	67	67	0.94
Latrine (%)	70	74	0.48

Table 2: Percentage of Children with Respiratory Illness Observed during Home Visits, by Stove Type, April 2010-April 2011, Nyando District, Kenya

	Episodes/Visits(%)					
	Jiko	**3-stone firepit**	**Crude RR (95%CI)**	**Crude RR* (95%CI)**	**Adjusted RR*,¥ (95%CI)**	**Adjusted RR*,+ (95%CI)**
Cough	9/ 619 (1.5%)	95/ 3232 (2.9%)	0.5 (0.3, 0.97)	0.5 (0.2, 1.0)	0.5 (0.3, 1.2)	0.6 (0.3, 1.3)
Pneumonia	6/ 619 (1.0%)	55/ 3232 (1.7%)	0.6 (0.3, 1.3)	0.6 (0.2, 1.4)	0.7 (0.3, 1.8)	0.7 (0.3, 1.9)
Severe Pneumonia	2/ 619 (0.3%)	18/ 3232 (0.5%)	0.6 (0.1, 2.5)	0.6 (0.2, 2.3)	0.8 (0.2, 3.1)	1.1 (0.3, 4.1)

*Accounting for repeated measures

¥ Covariates in generalized estimating equations multivariable model included the following household assets present at baseline that were significantly associated with jiko use: cell phone, iron roof, and bicycle

+Adjusted effect of exposure using propensity score analysis. Variables included in the propensity score analysis include household assets and demographic and hygiene and sanitation characteristics.

Table 3: Percentage of Children with Respiratory Illness Observed during Home Visits, Among Consistent Jiko and 3-Stone Firepit Users, April 2010-April 2011, Nyando District, Kenya

	Episodes/Visits (Percent)					
	Jiko Users (>80% of visits)	**3-Stone Firepit Users (100% of visits)**	**Crude RR (95% CI)**	**Crude RR* (95% CI)**	**Adjusted RR*,¥ (95% CI)**	**Adjusted RR*,+ (95% CI)**
Cough	8/ 537 (1.5%)	83/ 2473 (3.4%)	0.4 (0.2, 0.9)	0.4 (0.2, 1.2)	0.5 (0.2, 1.2)	0.5 (0.2, 1.5)
Pneumonia	4/ 537 (0.7%)	51/ 2473 (2.1%)	0.4 (0.1, 0.99)	0.4 (0.1, 0.9)	0.4 (0.2, 1.2)	0.4 (0.1, 1.4)
Severe Pneumonia	2/ 537 (0.4%)	16/ 2473 (0.7%)	0.6 (0.1, 2.5)	0.6 (0.1, .4)	0.8 (0.2, 3.2)	1.4 (0.4, 5.5)

*Accounting for repeated measures

¥ Covariates in generalized estimating equations multivariable model included the following household assets present at baseline baseline that were significantly associated with jiko use: cell phone, iron roof, and bicycle

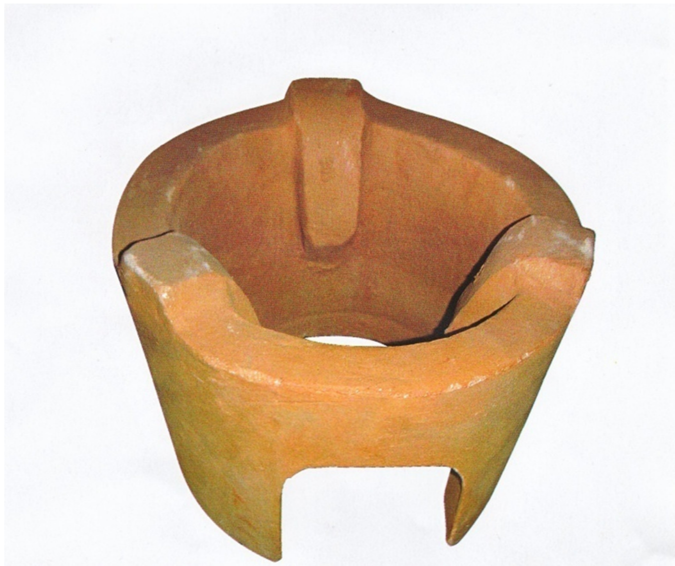
+Adjusted effect of exposure using propensity score analysis. Variables included in the propensity score analysis include household assets and demographic and hygiene and sanitation characteristics.

Table 4: Association Between Ownership of Household Assets and Respiratory Illness in Children, April 2010-April 2011, Nyando, District Kenya

Household Asset	Crude Cough RR* 95% CI	Adjusted Cough RR*,¥ 95% CI	Crude Pneu. RR* 95% CI	Adjusted Pneu. RR*,¥ 95% CI	Crude Severe Pneu. RR* 95% CI	Adjusted Severe Pneu. RR*,¥ 95% CI
Cell Phone	0.5 (0.3, 0.9)	0.5 (0.3, 0.9)	0.5 (0.3, 0.97)	0.5 (0.3, 1.0)	0.4 (0.1, 0.9)	0.3 (0.1, 0.9)
TV	0.4 (0.1, 0.9)	0.4 (0.2, 0.95)	0.2 (0.03, 1.4)	0.2 (0.03, 1.6)	-	-
Radio	0.6 (0.4, 1.1)	0.6 (0.3, 1.1)	0.6 (0.3, 1.1)	0.6 (0.3, 1.1)	0.2 (0.1, 0.5)	0.2 (0.1, 0.5)

*Accounting for repeated measures
¥Multivariable model adjusted effect of asset possession on respiratory illness by child sex, child age, jiko use, maternal education and hygiene and sanitation indicators. Each asset was a separate model.

Figure 1: Upesi Jiko



The specific dimensions are 30 centimeters for the top internal diameter, 26 cm for the bottom diameter, 15 centimeters for the diameter of the curved door, and 18 centimeters for the height of the firebox.

Figure 2: Percentage of Households Reporting Jiko Use April 2010-April 2011, Nyando District Kenya