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Impact of Locally-Produced, Ceramic Cookstoves on Respiratory Disease in Children in Rural Western Kenya

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Abstract.

Household air pollution is a risk factor for pneumonia, the leading cause of death among children < 5 years of age. From 2008 to 2010, a Kenyan organization sold ~2,500 ceramic cookstoves (*upesi jiko*) that produce less visible household smoke than 3-stone firepits. During a year-long observational study, we made 25 biweekly visits to 200 homes to determine stove use and observe signs of acute respiratory infection in children < 3 years of age. Reported stove use included 3-stone firepit only (81.8%), *upesi jiko* only (15.7%), and both (2.3%). Lower, but not statistically significant, percentages of children in *upesi jiko*-using households than 3-stone firepit-using households had observed cough (1.3% versus 2.9%, rate ratio [RR] 0.48, 95% confidence interval [CI]: 0.22–1.03), pneumonia (0.9% versus 1.7%, RR 0.60, 95% CI: 0.24–1.48), and severe pneumonia (0.3% versus 0.6%, RR 0.66, 95% CI: 0.17–2.62). *Upesi jiko* use did not result in significantly lower pneumonia rates. Further research on the health impact of improved cookstoves is warranted.

BACKGROUND

Pneumonia is the leading cause of death among children under 5 years of age in developing countries. Annually, ~70% of 1.6 million deaths from pneumonia among children occur in Southeast Asia and sub-Saharan Africa.[1,2] Cooking indoors with open fires, unprocessed biomass fuel, and inadequate ventilation is common in developing countries and generates high levels of household air pollution (HAP).[3] Women and their young children usually have the greatest exposures to HAP, including particulate matter, carbon monoxide, and nitrous oxides. Consequently, they are at greatest risk of adverse health effects from HAP.[4] One study estimated that young children who are exposed to HAP have a nearly 2-fold greater risk of acquiring pneumonia compared with young children without HAP exposure.[5] In 2000, Smith and others[6] estimated that 910,000 deaths from acute respiratory infections in children under 5 years of age were attributable to HAP.

To address the public health burden of HAP, a global effort is underway to develop and distribute improved cookstoves that reduce emissions of particulate matter. The Global Alliance for Clean Cookstoves, a public-private partnership, was formed in 2010 to encourage the adoption of 100 million clean cookstoves by 2020.[7] However, evidence

on the health benefits of improved cookstoves remains limited. One randomized controlled trial in Guatemalan children (RESPIRE) suggested that the use of improved cookstoves with chimneys that vented smoke outside the home did not significantly reduce the risk of physician-diagnosed pneumonia (rate ratio [RR] 0.84, 95% confidence interval [CI]: 0.63, 1.13).[8] However, the lack of effect was likely caused by either insufficient exposure reduction or insufficient statistical power. No published studies have reported on 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 easier to install, which is appealing for large-scale programs worldwide. Furthermore, because children can be exposed to cookstove smoke vented outside the home, vented smoke that re-enters the home, or smoke from fires built by neighbors, the advantage of vented over unvented cookstoves may be limited in the degree to which they can prevent particulate matter from being inhaled by children.[8]

In rural western Kenya, a survey conducted in 2008 in 60 villages found that nearly all households used traditional, open firepits surrounded by stones ("3-stone firepits") for cooking, and that > 95% burned unprocessed biomass (especially wood) for fuel.[9] Respondents reported concerns about the adverse health effects related to the use of 3-stone firepits, including breathing smoke (80%), burns (37%), and respiratory infections (11%).

Following the survey, a local non-governmental organization, the Safe Water and AIDS Project (SWAP) (www.swapkenya.org), began promoting the adoption of ceramic cookstoves called *upesi jiko* (Swahili for "quick stove") at the household level (Figure 1). *Upesi jikos* are made locally by pottery groups, and consist of a ceramic liner made from clay. The liners are built into a permanent gravel and mud matrix in the cooking area of a dwelling. The *upesi jiko* was selected for the project because of its presumed durability, local availability, and relative affordability (150–300 Kenya shillings, or US$2.00 to 3.00). The *upesi jiko* burns unprocessed biomass fuel (e.g., charcoal, wood, crop waste) and does not ventilate smoke outside the home. Community-based women's human immunodeficiency virus (HIV) self-help groups organized by SWAP have sold *upesi jikos* in their villages as an income-generating activity since 2008. In total, ~2,500 stoves were sold during a 3-year period.

Following the introduction of *upesi jiko* stoves, evaluations found that *upesi jiko* use noticeably reduced fuel use, cook times, visible smoke in the homes, and eye irritation.[9,10] A technical assessment using UCB Particle Monitors according to standard operating procedures outlined in the UCB Particle Monitor User Manual (http://berkeleyair.com/publications) determined that average emissions of ≤ 2.5 μm particles ($PM_{2.5}$) over 48 hours were decreased by 13%, from a geometric mean concentration of 125 μg/m^3 in households with 3-stone firepits to 109 μg/m^3 in households with *upesi jiko* ($P < 0.101$), a difference that was not statistically significant (Loo JD, CDC, unpublished data). Possible explanations for this finding included concurrent use of 3-stone firepits or other smoke-generating devices such as kerosene lamps during the particle monitoring periods. To assess the impact of *upesi jiko* on rates of respiratory disease in children, we took advantage of a randomized controlled trial of a water quality intervention in 20 rural Kenyan villages where the *upesi jiko* project was

co-located to conduct a 1-year, longitudinal observational study from April 2010 to April 2011.

METHODS

Study design.

From April 2010 to April 2011, we conducted a longitudinal observational study to examine the health impact of *upesi jiko* in a cohort of children < 2 years of age in households in 20 randomly selected villages. In all 20 villages, SWAP members had been promoting and selling *upesi jiko* stoves to local populations as an income generating activity since 2008.

Study population.

This evaluation took place in Nyando District, Nyanza Province, Kenya, where the mortality rate of children < 5 years of age was 149/1,000 live births, the highest in Kenya.[11] A 2002 study in western Kenya reported that 16.5% of deaths of children < 5 years of age were caused by pneumonia, the fourth most common cause of childhood death.[12] Twenty villages in Nyando District were randomly selected from 60 villages that had participated in the Nyando Integrated Child Health Project (NICHE).[13] All households in the study villages with a child < 12 months of age were invited to enroll.

Baseline data collection.

Households were enrolled between September 2009 and February 2010. Baseline data were collected from the child's primary caregiver on demographic characteristics, household assets, and water, sanitation, and hygiene practices.

Biweekly home visits.

Fieldworkers made a total of 25 biweekly home visits during 1 year of data collection. At each visit, the child's primary caregiver was interviewed to determine the stove primarily used in the home in the preceding week (with the option of reporting use of more than one stove), the type of fuel used in the preceding week, and the presence of cough and symptoms of pneumonia in the enrolled child in the preceding 24 hours. Fieldworkers were trained to diagnose pneumonia using the World Health Organization's (WHO) 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.[14]

Case definitions.

We defined cough as caregiver-reported cough without other symptoms in the enrolled child during the 24 hours preceding the home visit. We defined pneumonia as cough plus rapid respiratory rate, measured over 60 seconds with age-specific cutoff rates.[15] We defined severe pneumonia as cough plus chest wall indrawing or one or more of the following danger signs: convulsions, lethargy, unconsciousness, or inability to eat or drink.[15] Stove use categories were derived from reports of primary stove use over the preceding week. *Upesi jiko* use was defined as any use during the week preceding

interview. We defined consistent *upesi jiko* use as reported use of the stove by respondents at ≥ 80% of home visits.

Data analysis.

Using personal digital assistants (handheld computers), data were electronically recorded and uploaded into Microsoft *Access* databases (Microsoft Corp., Redmond, WA). Data were imported to SAS version 9.2 (SAS Institute Inc., Cary, NC) for statistical analysis. Households in which fewer than 19 (75%) of 25 home visits were completed were excluded from analysis. Characteristics of households that reported ever using an *upesi jiko* were compared with those that only reported using a 3-stone firepit, using χ^2 and Fisher's exact tests.

Crude rate ratios (RRs) and 95% confidence intervals (CIs) were calculated for cough, pneumonia, and severe pneumonia by dividing the percentage of ill children in households reporting *upesi jiko* use by the corresponding percentage in households reporting exclusive 3-stone firepit use. Because it is possible that consistent use of *upesi jikos* may have had a greater benefit than sporadic use, we also compared pneumonia rates in households that reported consistent *upesi jiko* use (≥ 80% of home visits) to households that exclusively used a 3-stone firepit.

The association between stove use and pneumonia was evaluated using general estimating equations with a banded correlation structure for the repeated measures. Household assets were a proxy measure for socioeconomic status (SES). We conducted a multivariate analysis to evaluate variables that were significantly associated ($P < 0.05$) with illness in univariate analysis. We constructed models examining associations between any *upesi jiko* use with three respiratory outcomes: cough, pneumonia, and severe pneumonia. We also constructed models examining consistent *upesi jiko* use, a constant stove status variable, with the same three respiratory outcomes. The RRs and 95% CIs are reported.

Ethics.

The protocol was approved by institutional review boards at the Kenya Medical Research Institute (protocol 1458) and the U.S. Centers for Disease Control and Prevention (CDC) (protocol 5039). Emory University's Institutional Review Board deferred to the CDC Institutional Review Board for approval of the protocol. We obtained informed consent from all participating households and removed personal identifiers from databases at the end of the study.

RESULTS

Baseline.

Of 200 enrolled households, 168 (84%) that completed > 75% of biweekly visits were included in the analysis. At baseline, the median age of respondents was 26 years (range 16–63 years). Nearly all (99%) respondents were female, and 65% had completed at least a primary education (Table 1). The median age of enrolled children was 5 months (range 0–11 months) and 53% were male. Respondents who reported ever using an *upesi jiko* were more likely to live in households with a cell phone (89% versus 59%, $P < 0.01$),

iron roof (72% versus 50%, $P < 0.01$), bicycle (75% versus 57%, $P = 0.02$), and electricity (5% versus 0%, $P = 0.05$) than respondents who reported exclusive use of a 3-stone firepit.

Biweekly home visits.

Of 3,950 total biweekly home visits made over the course of the study, exclusive 3-stone firepit use was reported at 3,232 visits (81.8%), exclusive *upesi jiko* use at 619 visits (15.7%), and use of both a 3-stone firepit and a *upesi jiko* at 91 visits (2.3%). Other stove use (8 visits, 0.2%) was excluded from analysis. Respondents reported burning unprocessed biomass fuel (e.g., wood, charcoal, crop waste) for cooking during the previous week at 99.9% of biweekly home visits, regardless of stove type used.

We collected health data on 168 children during 3,942 home visits over 25 rounds of household follow-up visits that took place during the 1-year study period. During this time, respondents reported a total of 104 episodes of cough, 61 episodes of pneumonia, and 20 episodes of severe pneumonia. Of 168 children included in the analysis, 52 (36%) had ≥ 1 episode of reported cough during 25 rounds of follow-up, 45 (27%) had ≥ 1 episode of pneumonia, and 18 (11%) had ≥ 1 episode of severe pneumonia.

In univariate analysis, a significantly lower percentage of children in households using *upesi jiko* reported cough compared with households using 3-stone firepits (1.3% versus 2.9%, RR 0.42, 95% CI: 0.20, 0.89). A lower, but not statistically significant, percentage of children in households using *upesi jiko* had pneumonia (0.9% versus 1.7%, RR 0.51, 95% CI: 0.21, 1.20 [Table 2]) and severe pneumonia (0.3% versus 0.6%, RR 0.51, 95% CI: 0.13, 1.99 [Table 3]) than children in households using 3-stone firepits. Similarly, a lower percentage of children in households that reported consistent use of *upesi jikos* had pneumonia (0.7% versus 2.1%, RR 0.33, 95% CI: 0.13, 0.86), and a lower, but not statistically significant, percentage had cough (1.5% versus 3.4%, RR 0.40, 95% CI: 0.16, 1.03) and severe pneumonia (0.3% versus 0.7%, RR 0.53, 95% CI: 0.13, 2.20) than children in households using 3-stone firepits. In households that had a cell phone, a potential proxy for SES, children were less likely to have cough (2.1% versus 3.9%, RR 0.53, 95% CI: 0.32, 0.87), pneumonia (1.2% versus 2.5%, RR 0.46, 95% CI: 0.26, 0.84), and severe pneumonia (0.3% versus 0.9%, RR 0.35, 95% CI: 0.14, 0.85) than children in households without a cell phone. The frequencies of cough, pneumonia, and severe pneumonia did not differ according to any other measured demographic characteristics, household assets, or sanitation and hygiene practices.

In all three multivariable models examining any *upesi jiko* use and adjusting for household cell phone possession, there were no significant associations between *upesi jiko* use and reported cough (RR 0.48, 95% CI: 0.22–1.03), pneumonia (RR 0.60, 95% CI: 0.24, 1.48), and severe pneumonia (RR 0.66, 95% CI: 0.17, 2.62). In these multivariable models, household possession of cell phones remained significantly associated with cough (RR 0.58, 95% CI: 0.35, 0.94), pneumonia (RR 0.49, 95% CI: 0.27, 0.89), and severe pneumonia (RR 0.36, 95% CI: 0.14, 0.89).

Similarly, in all three multivariable models evaluating consistent *upesi jiko* use and adjusting for household cell phone possession, there were no significant associations between *upesi jiko* use and reported cough (RR 0.44, 95% CI: 0.17, 1.14), pneumonia

(RR 0.38, 95% CI: 0.14, 1.03), or severe pneumonia (RR 0.68, 95% CI: 0.2, 3.0). Again, household possession of cell phones remained significantly associated with reported cough (RR 0.58, 95% CI: 0.35, 0.94); similar associations were not found for pneumonia (RR 0.64, 95% CI: 0.34, 1.2), or severe pneumonia (RR 0.46, 95% CI: 0.18, 1.22).

DISCUSSION

Results of this longitudinal, observational study suggest that a lower, though not statistically significant, percentage of children in households using *upesi jik*o experienced cough, fieldworker-diagnosed pneumonia, and severe pneumonia, than children in households that continued to use traditional open firepits for cooking. Although these differences were not significant, the effect sizes were similar to those found in the RESPIRE trial of improved cookstoves with chimneys.[8] Our study's household sample size was insufficient to provide adequate statistical power to detect significant differences in respiratory illness between households using *upesi jiko* and households using 3-stone firepits. The problem of inadequate sample size was compounded by lower rates of pneumonia in this population (1.4%) compared with, for example, those in the RESPIRE trial (2.3%).[8]

In our study, the consistently lower percentages of respiratory illness in children in households using *upesi jiko* were obtained despite the lack of evidence for a significant decrease in $PM_{2.5}$ emissions. An earlier study in the same Nyando District villages found that the 48-hour geometric average of $PM_{2.5}$ in households using *upesi jiko* was 13% lower than in households using 3-stone firepits, however this difference was not statistically significant despite reports by respondents, and observations by our study team, of reductions in visible smoke and eye irritation in households using *upesi jikos* (Loo JD, CDC, unpublished data). Current information suggests that improved cookstoves must reduce $PM_{2.5}$ particle emissions by at least 50% to reduce the risk of pneumonia in young children.[8] The RESPIRE trial was powered to detect a significant reduction in pneumonia assuming a 50% reduction in exposure to carbon monoxide (CO), a proxy for $PM_{2.5}$, in children.[17] Furthermore, the RESPIRE trial found that the risk of pneumonia changed the most at lower levels of exposure.[8] The $PM_{2.5}$ levels in households using *upesi jiko* in our study were, on average, about 4 times greater than WHO guideline values.[18]

The inconsistency between the estimated effect size in this study and the lack of evidence of reduction of $PM_{2.5}$ emissions in *upesi jiko*-using households in the same Nyando District villages has at least three potential explanations. First, the disease status of children in this study may have been misclassified because fieldworkers who diagnosed cases of pneumonia using IMCI guidelines were not trained clinicians. Chest x-ray and pulse oximetry, which would have improved diagnostic accuracy, were not used. Second, household $PM_{2.5}$ monitoring devices were used in an earlier evaluation of *upesi jiko* in our study villages to estimate HAP exposure as a surrogate for individual exposures to $PM_{2.5}$ in young children. It is likely that children's actual exposures were different from exposures measured at the household level, but the direction of these differences is unknown.[17] Third, factors other than $PM_{2.5}$ emissions may have been responsible for observed differences in the frequency of respiratory disease by household stove type. A qualitative study of the same villages found that *upesi jiko* users reported a

noticeable reduction in visible smoke in their homes compared with 3-stone firepits.[10] *Upesi jiko*s reportedly burned fuel more efficiently and cooked food faster than 3-stone firepits, which may have decreased exposure to smoke in the home.[9] Chemicals in wood smoke provoke inflammatory responses in the lungs, irritate airways, and suppress the immune system.[19] A reduction of exposure to airway irritants in the homes of *upesi jiko* users may have had a beneficial impact on respiratory symptoms.

Although *upesi jikos* were locally available, desirable, presumably durable, and actively promoted in this region, most households in this study did not possess one; *upesi jiko* use was reported at fewer than 20% of home visits. Economic constraints appeared to limit *upesi jiko* use, despite the relatively low cost of US$3.00 per unit. These findings highlighted the likelihood that the Global Alliance for Clean Cookstoves plan for market-based cookstove distribution may have limited success in reaching the poorest households where children are at greatest risk of pneumonia. For the Alliance to reach its goals, future dissemination plans will likely need to incorporate heavily subsidized or free distribution of improved cookstoves.[9,20]

Experience from this project has revealed important considerations for future efforts to scale up improved cookstoves. According to SWAP (www.swapkenya.org), over 2,500 *upesi jikos* were sold in 3 years, suggesting consistent demand for *upesi jikos*.[9] Convenience of use, expanded surface area on top of the stove for food preparation, reduced visible smoke in the home, reduced cook times, household cleanliness (e.g., decreased soot on the walls), and lower fuel expenditures were cited by users as benefits of the *upesi jiko*.[9,10] As higher efficiency stoves are developed, it will be important that designers also consider user acceptability in stove design to encourage stove adoption.

This study had several important limitations. First, because this was an observational study, *upesi jikos* were not randomly assigned to households. As a result, there appeared to be an uneven distribution of improved cookstoves by SES, which confounded our assessment of health impact. Households that had cell phones (a proxy for SES) were significantly more likely to use an *upesi jiko*, and children in those households may have been less likely to experience pneumonia caused by other factors related to their household's relatively higher SES. Second, data were collected in the context of another study. Consequently, data on other important potential risk factors for pneumonia, including malnutrition, lack of breastfeeding, lack of measles vaccination, household crowding, low birth weight, clinical malaria, and HIV status, were not collected. Third, precise classification of stove exposure was difficult because we relied on reports of stove use over a 1-week period. Because 3-stone firepits are free, any household with an *upesi jiko* could have also used a 3-stone firepit; combined stove use was, in fact, reported during some home visits. This practice, however, would have biased results toward the null. Finally, the villages in this study were selected in one division of one district of Nyanza Province, so the study population may not have been representative of either Nyanza Province or Kenya.

In conclusion, this study highlighted several key challenges to reducing the risk of respiratory illness by decreasing HAP exposures among young children. Our study is one of a few to examine the health impact of more efficient cookstoves, and the first to investigate the health impact of cookstoves that do not vent smoke outside the home. To date, none of the investigations of alternative cookstove use and respiratory illness have

found statistically significant associations. It is, therefore, apparent that the evidence base supporting the use of improved cookstoves as an effective intervention for childhood pneumonia remains weak at best. Further research into cookstove design, improved methodology for measuring $PM_{2.5}$ exposures, and adequately-powered health impact trials are urgently needed. Another challenge is economic. Although *upesi jiko* stoves are relatively inexpensive, and despite evidence of consistent consumer demand in villages where marketing was sustained over a 3-year period, less than one-fifth of households in this study reported *upesi jiko* use. Dissemination of improved cookstoves may require alternate strategies than the marketplace, such as free or highly subsidized distribution. A third challenge is the need to motivate and sustain changes in stove use practices. Despite the investment in *upesi jikos*, there was evidence of continued use of 3-stone firepits in some households. Achieving health impact through decreased HAP may require exclusive use of more efficient cookstoves. Despite these challenges, the ability of local artisans to produce, market, and sell substantial numbers of inexpensive cookstoves with improvements over traditional cooking technology is a promising development in the search for interventions to reduce the burden of HAP and pneumonia in the developing world.

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*OUTLEGENDS*F1*FIGURE 1. *Upesi jiko*. The specific dimensions are 30 cm for the top internal diameter, 26 cm for the bottom diameter, 15 cm for the diameter of the curved door, and 18 cm for the height of the firebox. This figure appears in color at www.ajmth.org.

TABLE 1

Baseline demographic characteristics of caregivers and enrolled children < 3 years of age; household assets; and sanitation and hygiene practices, among users of *upesi jiko* stoves and 3-stone firepits—Nyando District, Kenya

Characteristics	Any reported *upesi jiko* use	3-Stone firepit only (100% use)	*P* value
% of households (*N*)	36% (61)	63% (105)	–
Primary caregiver Female (%)	100	98	0.53
Median age (yrs)	26	26	0.96
Completed primary school (%)	73	62	0.13
Child			
Male (%)	54	52	0.83
Mean age (mo.)	6	5	0.66
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
Television (%)	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
Sanitation and hygiene practices			
Soap observed (%)	92	87	0.37
Caregiver demonstrated proper hand washing (%)	67	67	0.94
Latrine (%)	70	74	0.48

TABLE 2

Percent of home visits with episodes of pneumonia in children < 3 years of age, by household characteristics, April 2010–April 2011, Nyando District, Kenya

	Households with characteristic			Households without characteristic				
Household characteristic	Pneumonia episodes	Total visits	%	Pneumonia episodes	Total visits	%	Rate ratio*	95% CI
Any *upesi jiko* use†	6	710	0.08	55	3232	1.7	0.51	0.21, 1.20
Consistent *upesi jiko* use‡	4	585	0.7	51	2473	2.1	0.33	0.13, 0.86§
Has cell phone	32	2776	1.2	29	1174	2.5	0.46	0.26, 0.84§
Has bicycle	37	2527	1.5	24	1423	1.7	0.85	0.47, 1.56
Iron roof on house	29	2307	1.3	28	1571	1.8	0.70	0.38, 1.30

* Accounting for repeated measures.

† Reported *upesi jiko* use in the past week versus reported 3-stone firepit use in the past week.

‡ Households that used an *upesi jiko* > 80% of visits versus households that only used the 3-stone firepit.

§ Statistically significant ($P < 0.05$).

TABLE 3

Percent of home visits with episodes of severe pneumonia in children < 3 years of age, by household characteristics, April 2010–April 2011, Nyando District, Kenya

Household characteristic	Households with characteristic	Households without characteristic	Rate ratio*	95% CI

	Severe pneumonia episodes	Total visits	%	Severe pneumonia episodes	Total visits	%		
Any *upesi jiko* use†	2	708	0.3	18	3214	0.6	0.51	0.13, 1.99
Consistent *upesi jiko* use‡	2	583	0.3	16	2457	0.7	0.53	0.13, 2.20
Cell phone Possession	9	2767	0.3	11	1163	0.9		0.14, 0.85*§
Bicycle Possession	12	2527	0.5	8	1423	0.6	0.84	0.33, 2.14
Iron roof	9	2307	0.4	10	1571	0.6	0.62	0.25, 1.57

* Crude rate ratio accounting for repeated measures.

† Reported *upesi jiko* use in the past week versus reported 3-stone firepit use in the past week.

‡ Households that used an *upesi jiko* > 80% of visits versus households that only used the 3-stone firepit.

§ Statistically significant ($P < 0.05$).

CI = confidence interval.

Figure 1