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Biomass fuel use and the risk of asthma in Nigerian children

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Summary
Background: Biomass fuel smoke exposure contributes to respiratory infections in childhood, but its association with asthma has not been established. We studied the relationship of biomass fuel use with asthma symptoms and lung function in Nigerian children.
Methods: A cross-sectional study was performed in 299 village children aged 5–11 years in North Central Nigeria. Data were collected regarding the cooking fuels used and duration of daily smoke exposure in the cooking area. Asthma symptoms were assessed with a modified International Study of Asthma and Allergies in Childhood (ISAAC) questionnaire, and lung function was assessed with spirometry.
Results: The prevalence of a lifetime history of wheeze was 9.4% (95% CI: 6.3%–13.2%). Fourteen children (4.7%) had airway obstruction (FEV_1/FEV_6 <85%). Female subjects had lower FEV_1 and FEV_6 (110 % and 120% percent predicted, respectively) than males (121% and 130%, respectively, P <0.001 for both differences). Advancing age was associated with a relative decline in the predicted value of FEV_1 of 7.8 % per year ($r = -0.61$; $P < 0.001$). Children in families that used firewood daily did not have a significantly increased likelihood of asthma-related symptoms (OR = 2.36, 95% CI: 0.66–8.44). Similarly, airway obstruction did not differ significantly between children in households that did and did not use firewood daily (mean FEV_1/FEV6 of 0.95 and 0.97, respectively; $P = 0.41$).
Conclusion: Reported smoke exposure was not associated with an increased risk of asthma symptoms or airway obstruction. However, lifetime smoke exposure may explain the reduction in spirometric values in female subjects and with advancing age.

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Introduction

It is estimated that 2 million people die prematurely each year from smoke produced by open fires and improvised stoves, leading to 4% of the global health burden [1,2]. In today's world roughly half, and close to 90% of those living in rural households, still rely on biomass fuels (BMF) [2]. This translates into 500 million households or 2.4 billion people worldwide using unprocessed BMF for cooking and heating [1]. Biomass fuels consist of coal, wood, crop residues, or any plant or animal material burned in household stoves or open fires, often with inadequate ventilation [2–4]. Inefficient BMF combustion creates substantial smoke, carbon monoxide, hydrocarbons, free radicals, oxygenated organics and particulate matter [5,6].

Exposure to biomass smoke doubles the risk of pneumonia and other acute lower respiratory infections, and contributes to over 800,000 deaths in children under five [7,8]. In rural Africa, exposure to biomass smoke in young children is frequent, because they are carried on their mothers' backs or remain close to their mothers during cooking. Older girls commonly help in cooking, increasing their exposure risk.

Asthma is potentially associated with exposure to biomass smoke. Airway obstruction is caused by bronchospasm, airway inflammation, and mucus plugging. Symptoms of wheezing, cough, and dyspnea may be provoked by inhalation of smoke, leading to inflammation and bronchospasm. Exposure to biomass smoke has been associated with respiratory diseases like chronic obstructive pulmonary disease, asthma, tuberculosis, and lung cancer in adults. During episodes of high pollution, asthma and respiratory related hospital admissions increase [9,10]. However, individual studies report conflicting results regarding the association of biomass smoke exposure and asthma [7]. The findings of a meta-analysis of four studies of asthma in children and biomass smoke exposure were inconclusive [7].

Although the evidence for particulate air pollution in the pathogenesis of asthma is suggestive, the link between asthma and biomass smoke exposure has not been confirmed. The relationship of biomass smoke exposure with pulmonary function has not been previously reported in children in Nigeria, the most populous country in Africa. In order to clarify the relationship of biomass smoke exposure and asthma in African children, we conducted a community-based cross-sectional study to determine the association between biomass smoke exposure in children and the risk of asthma symptoms and airway obstruction in a rural Nigerian village.

Methods

Eligible children, aged 5–11 years, were recruited from households in Kisayhip village near the city of Jos, in North Central Nigeria. Kisayhip is on rocky plateau with an altitude of approximately 1000 m. Data were collected during the dry season in February 2012. A trained community health worker, who resided in the village and was fluent in English and the local languages of Rukuba and Hausa, accompanied the study investigator. All households were visited in an area of the village prior to moving to the next cluster of homes, beginning at one end of the village and progressing to the other. As no list of households was available, we did not use a formal method of random selection. Households were revisited up to four times to include all eligible children that were missing on previous visits. A household was defined as all persons who eat from the same pot. Acutely ill children, children with obvious physical or mental disabilities, and children unable to perform acceptable spirometry were excluded. The study was approved by the village chief and by the Jos University Teaching Hospital Institutional Health Research Ethical Committee. Written informed consent was obtained from the parent or guardian of each child enrolled.

Data were collected about cooking fuels, the cooking environment and the number of family members who smoked cigarettes. A modified version of the questionnaire developed by the International Study of Asthma and Allergies in Childhood (ISAAC) was used to identify asthma symptoms [11]. Wheezing was defined as reported wheezing in the past 12 months and wheeze ever, which were coded positive if the subject answered "yes" to wheezing or whistling in the chest. Cough was defined as the presence of a dry cough not associated with a cold or chest infection. Lung auscultation was performed, and the presence of rhonchi or wheezing was classified as adventitious breath sounds. The variable "symptoms and signs of asthma" was considered positive if wheeze, cough, or adventitious breath sounds were present, based on the aforementioned definitions. Weight was measured to the nearest half kilogram with a platform scale. Height was measured to the nearest quarter inch by having children stand against a wall and using a tape measure.

Pulmonary spirometry was performed with a compact spirometer with a pediatric mouthpiece (Vitalograph COPD-6, Ennis, Ireland). Spirometric measurements included the forced expiratory volume in 6 s (FEV_6), forced expiratory volume in 1 s (FEV_1), and FEV_1/FEV_6, the ratio of volumes expressed as a percentage to quantify the degree of airway obstruction. Spirometry was performed by a respiratory therapist (JDT) in a standing position with the child's arms at the sides. Nose clips were used to prevent nasal exhalation. The interviewer was trained in proper use of the spirometer and instructed children on proper technique, which was demonstrated to the child. Efforts were repeated up to ten times, or until a good effort and technique were observed. Spirometric values for three acceptable efforts were recorded, and the effort with the greatest values was used for analysis. Based on the American Thoracic Society guidelines for the interpretation of spirometry, obstruction was defined as FEV_1/FEV_6 ratio less than 85 percent of predicted [12]. Predicted spirometric reference values for gender, age, and height were based on African Americans in the National Health and Nutrition Examination Survey (NHANES III) [13].

Statistical methods

Epi Info 3.5.3 (CDC, Atlanta, Georgia) and SPSS 17 (IBM, Armonk, New York) were used for data analysis. Spirometric values were compared between those using different fuel types and differing duration of exposure with Kruskal—Wallis or Mann—Whitney tests. Univariate analyses were performed to test associations between potential risk factors and asthma symptoms. Multiple logistic regression models were constructed to adjust for potential confounding factors. For dichotomous independent variables such as wheeze and cough, odds ratios and 95% confidence intervals were calculated. P-values <0.05 were considered significant for all analyses. Height and weight standardized z-scores were calculated using Epi Info with the Center for Disease Control (CDC) 2000 growth curves as reference.

Results

Among 213 households, 166 had children aged 5—11 years who performed acceptable and reproducible spirometry, resulting in a total of 299 children enrolled. Seven children were excluded: one due to cognitive impairment and inability to perform acceptable spirometry, and six were unavailable after multiple visits. Characteristics of the study subjects are shown in Table 1. Stunting was present in 43 (14.4%), and wasting was present in 26 (8.7%). The prevalence of reported wheezing in the past 12 months was 8.7%, and 6.4% had wheezing or rhonchi on auscultation. A total of 218 children (73%) were in households that used solely firewood, and only 6% never used firewood. The remainder used a mixture of firewood, charcoal, kerosene, and liquefied petroleum gas. Mean daily biomass smoke exposure was greater in females than males (1.51 and 1.06 h, respectively, $P < 0.001$).

Spirometric values of children are presented in Table 2. The overall mean values of FEV_1 for the three consecutive acceptable efforts were 1.25 ± 0.37, 1.28 ± 0.38, and 1.30 ± 0.38 L, indicating good reproducibility of maximal effort. Mean values of FEV_1 for the three consecutive efforts did not differ by more than 6% of the mean in any age group or gender. The mean FEV_1 and FEV_6 values in all ages and subgroups were greater than 100% of the predicted values for the reference African-American population. With airway obstruction defined as an FEV_1/FEV_6 ratio less than 85%, only 14 children (4.7%) had airway obstruction. Female subjects had lower FEV_1 and FEV_6 (as percent predicted) than males. Advancing age was associated with a relative decline of 7.8% per year in the predicted value of FEV_1 ($r = -0.61$; $P < 0.001$). This decline did not differ by gender ($P = 0.41$ for interaction). A lower FEV_1 and FEV_6 (as percent predicted) were associated with the reported duration of daily smoke exposure ($P < 0.001$), but airway obstruction was not ($P = 0.44$). However, when firewood smoke exposure was defined as at least 30 min of smoke exposure more than 3 days per week, no significant relationship of smoke exposure with asthma symptoms or pulmonary function was present in univariate analysis.

The relationships of various characteristics adjusted for age with signs and symptoms of asthma are shown in Table 3. Age, gender, and smoke exposure characteristics were not significantly associated with asthma symptoms or signs. Stunting was associated with a history of wheeze (OR = 2.7, 95% CI: 1.0—7.7). After adjusting for gender, age, and stunting in a multivariate model, neither the number of hours of smoke exposure nor daily use of firewood were significantly associated with the risk of asthma symptoms (OR = 1.03, 95% CI: 0.23—4.64) and (OR = 2.12, 95% CI: 0.58—7.74) respectively (Table 4, Model 3). There was no significant interaction between age and gender in their relationship with percent predicted FEV_1 or FEV6. Similarly, airway obstruction did not differ significantly between children in households that did and did not use firewood daily (mean FEV_1/FEV6 of 0.95 and 0.97, respectively; $P = 0.41$).

Table 1 Characteristics of study subjects.

Characteristic	No. (%)
Gender	
Male	135 (45.2)
Female	164 (54.8)
Age (years)	
5	55 (18.4)
6	40 (13.4)
7	45 (15.1)
8	41 (13.7)
9	25 (8.4)
10	40 (13.4)
11	53 (17.7)
Nutritional status	
Height-for-age z-score below −2.0	43 (14.4)
Weight-for height z-score below −2.0	26 (8.7)
Reported wheeze	
Lifetime	28 (9.4)
In the past 12 months	26 (8.7)
Dry cough (apart from cold or chest infection)	59 (19.7)
Wheezing or rhonchi on auscultation	19 (6.4)
Cigarette smokers in the house	
None	238 (79.6)
One	58 (19.4)
Two or more	3 (1)
Reported biomass smoke exposure (hours/day)	
0	43 (14.4)
0.5	4 (1.3)
1	134 (44.8)
2	100 (33.4)
3	17 (5.7)
4	1 (0.3)
Firewood use (times/week)	
Never[a]	18 (6)
1 to 3	15 (5)
4 to 6	48 (16)
7	218 (73)
Household population (Mean ± SD)	8.3 ± 3.7
FEV_1/FEV6%	
<85	14 (4.7)
85—100	285 (95.3)

[a] Other fuels included kerosene, charcoal, or liquefied petroleum.

Discussion

We did not demonstrate an association of biomass smoke exposure with either reduced pulmonary function or

Table 2 Spirometric values in Nigerian children.

Characteristic	FEV_1(L) (%predicted)	*P* value[a]	FEV6(L) (%predicted)	*P* value[a]	FEV_1/FEV6(%)	*P* value[a]
Gender		$P < 0.001$		$P < 0.001$		$P = 0.75$
M	1.34 ± 0.36 (130 ± 27)		1.46 ± 0.43 (120 ± 22)		95 ± 5	
F	1.35 ± 0.39 (121 ± 27)		1.46 ± 0.45 (110 ± 15)		96 ± 9	
Age (years)		$P < 0.001$[c]		$P < 0.001$[c]		$P < 0.001$[c]
5	0.95 ± 0.22 (151 ± 34)		1.01 ± 0.24 (120 ± 23)		97 ± 4	
6	1.09 ± 0.18 (139 ± 22)		1.14 ± 0.19 (119 ± 19)		98 ± 2	
7	1.19 ± 0.18 (133 ± 22)		1.30 ± 0.22 (124 ± 21)		95 ± 6	
8	1.39 ± 0.23 (122 ± 19)		1.48 ± 0.26 (115 ± 19)		96 ± 4	
9	1.51 ± 0.20 (109 ± 11)		1.64 ± 0.24 (106 ± 13)		95 ± 5	
10	1.55 ± 0.25 (108 ± 13)		1.71 ± 0.31 (109 ± 14)		94 ± 5	
11	1.79 ± 0.32 (106 ± 12)		2.00 ± 0.38 (107 ± 13)		95 ± 14	
Stunting (HAZ < -2)		$P = 0.51$		$P < 0.01$		$P = 0.64$
Yes	1.22 ± 0.26 (127 ± 35)		1.32 ± 0.30 (124 ± 26)		96 ± 8	
No	1.36 ± 0.39 (125 ± 26)		1.48 ± 0.46 (113 ± 17)		95 ± 4	
Wasting (WHZ < -2)		$P = 0.58$		$P < 0.01$		$P = 0.95$
Yes	1.10 ± 0.26 (120 ± 22)		1.20 ± 0.30 (107 ± 14)		95 ± 5	
No	1.37 ± 0.38 (126 ± 28)		1.48 ± 0.44 (116 ± 19)		96 ± 7	
Reported wheeze		$P = 0.35$		$P = 0.21$		$P = 0.32$
Yes	1.25 ± 0.37 (127 ± 20)		1.36 ± 0.43 (117 ± 17)		95 ± 5	
No	1.35 ± 0.37 (125 ± 28)		1.47 ± 0.44 (115 ± 19)		96 ± 8	
Reported biomass smoke exposure (hours/day)		$P < 0.001$[c]		$P < 0.001$[c]		$P = 0.83$[c]
0	1.12 ± 0.31 (134 ± 29)		1.21 ± 0.35 (119 ± 23)		95 ± 5	
0.5–1	1.24 ± 0.32 (131 ± 28)		1.33 ± 0.37 (117 ± 19)		96 ± 4	
2	1.52 ± 0.35 (118 ± 22)		1.67 ± 0.44 (113 ± 17)		95 ± 11	
≥3	1.70 ± 0.38(106 ± 21)		1.82 ± 0.41 (104 ± 14)		95 ± 3	
Firewood use (days/week)		$P = 0.66$[c]		$P = 0.63$[c]		$P = 0.63$[c]
Never	1.27 ± 0.35 (121 ± 24)		1.38 ± 0.40 (111 ± 20)		95 ± 5	
1 to 3	1.42 ± 0.36 (124 ± 23)		1.53 ± 0.42 (113 ± 20)		95 ± 7	
4 to 6	1.33 ± 0.42 (121 ± 30)		1.44 ± 0.48 (110 ± 21)		98 ± 14	
7	1.35 ± 0.37 (127 ± 27)		1.46 ± 0.44 (116 ± 18)		95 ± 5	
Exposed to biomass smoke[b]		$P = 0.13$		$P = 0.85$		$P = 0.58$
Yes	1.38 ± 0.38 (125 ± 27)		1.50 ± 0.45 (115 ± 18)		96 ± 8	
No	1.21 ± 0.34 (129 ± 27)		1.31 ± 0.39 (116 ± 22)		95 ± 5	

Abbreviations: FEV_1 = forced expiratory volume in one second; FEV6 = forced expiratory volume in six seconds; HAZ = height-for-age z-score; WHZ = weight for height z-score.

[a] Values are displayed as means ± SD. *P*-values are determined for the comparison of % predicted values by Kruskal–Wallis or Mann–Whitney test.

[b] Exposed children had at least 30 min of firewood smoke exposure more than three days per week.

[c] *P*-values for variables with more than 2 categories were assessed by linear regression and refer to the percent predicted values.

asthma symptoms in Nigerian children. The relationship of biomass smoke exposure with asthma risk has been debated, and previous studies have been inconclusive [7,14,15]. In a case-control study in Kenya, indoor air pollution was associated with asthma among 9–11 year olds with an adjusted odds ratio of 2.5 [16]. Asthma was defined as either a history of asthma, persistent wheeze, or a decline of at least 10% in forced expiratory volume in one second (FEV_1) at five or ten minutes after exercise [16]. Exposure was identified by visible air pollution within and around the house. In contrast, a case-control study in Nigeria found an unexplained protective effect of biomass smoke exposure and asthma risk [17]. The investigators found a significant association of asthma with having moldy and damp bedrooms, use of mosquito coils, having household pets, environmental tobacco smoke, and the presence of cockroaches or rodents [17].

We found a relatively low 8.7% 12-month prevalence of reported wheezing compared with those of high income countries. In the USA, Australia, and the UK, prevalence rates for wheeze are generally greater for children in similar age groups: 13.4%, 29.7, and 32.2%, respectively [18]. Another Nigerian study of 6–7 year-old children reported a 12-month prevalence of wheeze of 5.1 percent [19]. A low prevalence of wheeze has been reported in other African countries, with the prevalence of wheeze ranged from 8 to 14% [18]. Similarly, we found a low 4.7% prevalence of airway obstruction based on spirometry in Nigerian children, compared with an approximately 20% estimated prevalence of nonspecific airway reactivity in the general pediatric population in the USA [20]. The low prevalence of wheeze fits the "hygiene hypothesis" [21], which asserts that early childhood exposure to infections and intracellular pathogens may be advantageous later in

Table 3 Relationship of clinical characteristics with asthma symptoms and signs.

Characteristic	Wheeze ever		Cough		Adventitious breath sounds		Symptoms[a]	
	Yes		Yes	OR[c] (95% CI)	Yes	OR[c] (95% CI)	Yes	OR[c] (95% CI)
Gender								
F	17	Reference	37	Reference	7	Reference	51	Reference
M	11	0.78 (0.35–1.75)	22	0.66 (0.37–1.20)	12	2.19 (0.84–5.72)	33	0.70 (0.42–1.18)
Stunting								
No	21	Reference	48	Reference	16	Reference	70	Reference
Yes	7	2.79 (1.01–7.68)	11	1.52 (0.69–3.35)	3	1.13 (0.31–4.04)	14	1.37 (0.66–2.85)
Biomass smoke exposure (hours)								
0	3	Reference	6	Reference	3	Reference	10	Reference
0.5–1	16	1.83 (0.49–6.72)	28	1.54 (0.59–4.06)	9	0.93 (0.24–3.60)	40	1.42 (0.63–3.18)
2	9	1.40 (0.33–5.96)	22	1.82 (0.64–5.22)	6	0.85 (0.20–3.57)	30	1.67 (0.68–4.06)
≥3	0	0 (0)	3	1.46 (0.28–7.44)	1	0.78 (0.08–8.09)	4	1.20 (0.29–5.00)
Firewood use (days/week)								
Never	3	Reference	2	Reference	1	Reference	3	Reference
1 to 3	0	0.00 (0)	2	1.22 (0.15–10.00)	0	0 (0)	2	0.77 (0.11–5.40)
4 to 6	4	0.47 (0.09–2.42)	3	0.57 (0.09–3.74)	4	1.55 (0.16–14.83)	9	1.17 (0.28–4.96)
7	21	0.55 (0.14–2.08)	52	2.61 (0.56–11.81)	14	1.17 (0.14–9.42)	70	2.44 (0.68–8.76)
Exposed to biomass smoke[b]								
No	6	Reference	10	Reference	4	Reference	15	Reference
Yes	22	1.20 (0.45–3.18)	49	1.57 (0.74–3.36)	15	1.09 (0.35–3.39)	69	1.59 (0.82–3.06)

[a] Symptoms and signs are any combination of the following: wheeze, cough, or adventitious breath sounds.
[b] Exposed children had at least 30 min of firewood smoke exposure more than three days per week.
[c] Adjusted for age.

life [21,22]. Exposure *in utero* or early infancy may promote T-cells to differentiate and protect against later atopy [6]. African children, often living in close proximity to domesticated animals, are exposed to a vast array of endotoxins, mycobacteria, helminths, and gastrointestinal pathogens. A growing body of evidence indicates that exposure to some of these pathogens provides a protective effect on the development of asthma [22,23]. Swedish children who had a pet in the first year of life had less asthma and allergic rhinitis [24].

Other factors could explain the low prevalence of wheeze and airway obstruction in Nigerian children. Relatively low levels of outdoor air pollution in rural Nigeria could potentially contribute to a lower prevalence of asthma than in high-income countries. More time spent indoors and less outdoor physical activity could lead to a greater prevalence of asthma in western societies compared with African populations [22]. Most children had predicted values of FEV_1 and FEV6 that were greater than expected, based on the spirometric reference population of African-American children in the U.S. National Health and Nutrition Examination Survey (NHANES III). For the reasons noted above, this reference group may not be directly comparable to African children. Survival bias could also explain the relatively high pulmonary function in Nigerian children. According to UNICEF the under-five mortality in Nigeria is 14.3%, and many of these deaths are due to acute respiratory infections [25]. Children with poor lung function may have already died, leaving children with healthier lungs alive.

We found evidence of a decline in expected FEV_1 and FEV_6 with increasing age and female gender. Age could be a more accurate measure of long-term cooking smoke exposure than recall by the parent of average number of hours spent around the fire. Female children generally spend more time helping with cooking than male children, thus resulting in more hours of exposure to BMF smoke. This could explain the decline in pulmonary function among females. Investigators in rural Ecuador reported lower FEV_1 and FVC in children aged 7–15 years living in households that cooked with BMF only [26]. Biomass smoke exposure may impair lung growth in children. This observation is consistent with a similar effect of air pollution on lung growth in children between 10 and 18 years of age [27,28].

Strengths of this study included utilization of both the validated ISAAC questionnaire and spirometry to identify children with asthma. Unlike case-control or hospital-based studies, our exhaustive community-based sampling provided accurate prevalence data for asthma symptoms and spirometric values for the population. Although peak flow and spirometric values have been previously reported in healthy Nigerian children [29,30], this is the first report of the relationship of pulmonary function with BMF exposure in young children in Africa, where BMF utilization is widespread.

Several limitations of the study deserve mention. A larger sample size would have had greater power to detect smaller differences. Our study had 80% power to detect a difference of 12% in the predicted FEV_1 between children who were or were not exposed to biomass smoke most days of the week, and it had 80% power to detect an increase of prevalence of asthma symptoms from 9.8% to 14% with smoke exposure. Some children with asthma were possibly not identified by questionnaire or spirometry. The accuracy

Table 4 Multivariate analysis of the relationship of characteristics with signs and symptoms of asthma.[a]

Characteristic	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Reported biomass smoke exposure (hours/day)			
0	Reference	Reference	Reference
0.5–1	1.35 (0.61–3.00)	1.13 (0.50–2.56)	1.15 (0.50–2.65)
2	1.41 (0.62–3.23)	1.18 (0.51–2.76)	1.29 (0.51–3.28)
≥3	0.94 (0.25–3.52)	0.94 (0.25–3.60)	1.03 (0.23–4.64)
Firewood use (days/week)			
Never		Reference	Reference
1 to 3		0.78 (0.11–5.43)	0.70 (0.10–5.06)
4 to 6		1.17 (0.27–5.01)	1.03 (0.24–4.49)
7		2.23 (0.65–8.34)	2.12 (0.58–7.74)
Gender			
F			Reference
M			0.71 (0.41–1.24)
Age (Years)			
5			Reference
6			0.93 (0.37–2.31)
7			0.80 (0.33–1.98)
8			0.88 (0.35–2.23)
9			0.60 (0.20–1.86)
10			0.63 (0.23–1.73)
11			0.62 (0.23–1.65)
Stunting			
No			Reference
Yes			1.27 (0.61–2.68)

[a] Symptoms and signs of asthma are any combination of the following: wheeze, cough, or adventitious breath sounds.

of the ISAAC questionnaire for the identification and diagnosis of asthma has been previously validated [31]. Methacholine challenge would have been required to confirm asthma in children with symptoms suggestive of asthma but without airway obstruction. Spirometry was more likely to identify persistent asthma than mild, intermittent asthma. Hand held spirometry compared favorably with office spirometry [32]. The use of both methods in this study was more sensitive than using either method alone, and provides both a subjective and objective measure. The reported hours of biomass smoke exposure may have been an inaccurate estimate of actual duration of smoke exposure, and the age and gender may have been a better measure of lifetime biomass smoke exposure that was not subject to potential recall bias. We only assessed biomass smoke exposure related to cooking and not potential exposure to BMF use for heat or light. We found that some households burned charcoal for heating during cooler months. We did not directly measure concentrations of particulate matter or toxic products of combustion in the cooking area.

Conclusion

Despite the benefit of minimizing childhood exposure to BMF, we found no association of biomass smoke exposure with either reduced pulmonary function or asthma symptoms in Nigerian children. The relationship of BMF exposure with pulmonary function has not been previously reported in African children, and it was notable that pulmonary function of Nigerian children was superior to the African-American reference group, and the prevalence of reported wheeze was low. Although we did not confirm a relationship between measures of smoke exposure and asthma, the decline in predicted FEV_1 with age and lower values in females could still be related to a detrimental effect of biomass smoke exposure or other environmental pollutants on lung growth. Prospective cohort studies with a larger sample size will likely be required to confirm an association between biomass smoke exposure and decline in pulmonary function in children.

Author contributions

JDT, AE, AM, and TDT were all involved in study design and questionnaire development. JDT performed data collection for the whole study. JDT, AE, and TDT were involved in analysis plan and JDT performed the statistical analyses. JDT drafted the initial paper and AE, AM and TDT participated in paper revision. All authors approved the final version of the manuscript. JDT confirms he had full access to all the data in the study and that he takes responsibility for the integrity of the data and the accuracy of the data analysis.

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