CHEST

Indoor Particulate Matter < 2.5 μm in Mean Aerodynamic Diameter and Carbon Monoxide Levels During the Burning of Mosquito Coils and Their Association With Respiratory Health

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BACKGROUND: An estimated 700 million people suffer from mosquito-borne diseases worldwide. Various types of mosquito repellents are widely used to prevent mosquito bites. The objectives of this study were (1) to measure the indoor levels of particulate matter < 2.5 μm in mean aerodynamic diameter ($PM_{2.5}$) and carbon monoxide (CO) during the burning of mosquito coils (MCs) and study the impact of indoor ventilation patterns; and (2) to study and compare the prevalence of respiratory ailments in homes using different types of mosquito repellents.

METHODS: Indoor $PM_{2.5}$ and CO levels were measured inside a bedroom during the burning of MCs keeping the window and/or door open/closed over a 6-h duration. A cross-sectional survey was conducted in three villages where 465 individuals were administered a questionnaire that captured demographic details, type and duration of mosquito repellents used, and prevalence of respiratory symptoms and diseases.

RESULTS: Fifty-three percent of the subjects burned MCs on most days of the week, and 63% did so with their doors and windows closed. Burning of MCs produced very high levels of $PM_{2.5}$ (1,031 μg/m^3 mean, 1,613 μg/m^3 peak) and CO (6.50 parts per million (ppm) mean, 10.27 ppm peak) when both the door and window were closed. These levels reduced by around 50% when the window was opened and > 95% when both the window and the door were opened. The prevalence rates of respiratory symptoms and diseases were higher in subjects using MCs, although not statistically significant. Those living in smaller homes and using MCs had significantly greater morbidity.

CONCLUSIONS: Burning of MCs produces indoor levels of $PM_{2.5}$ and CO that are higher than those reported during the burning of biomass fuels for cooking purposes and may be associated with respiratory morbidity.
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KEY WORDS: air pollution; community health; COPD; smoke; upper airways

ABBREVIATIONS: CO = carbon monoxide; MC = mosquito coil; PEFR = peak expiratory flow rate; $PM_{2.5}$ = particulate matter < 2.5 μm in mean aerodynamic diameter; ppm = parts per million; WCDC = window closed-door closed; WODC = window open-door closed; WODO = window open-door open

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Mosquito bites in humans infect around 700 million people every year with parasites and viruses that cause malaria, dengue, and Japanese encephalitis, which leads to several million deaths.[1,2] Mosquito coils (MCs) are the most widely used repellents in Asia, Africa, and South America. An estimated 40 to 50 billion MCs are sold every year to around 2 billion people across the globe, and these offer about 80% protection from mosquito bites.[3,4]

Pyrethrum is the main chemical ingredient present in the MC and is obtained from the pyrethrum daisy flower or from the synthetic pyrethroid, *d*-trans allethrin. It accounts for only 0.3% to 0.4% of the MC mass, whereas the bulk of the coil is made up of wood powder, coconut shell powder, or joss powder, along with binders, dyes, oxidants, and other additives that help the coil to smolder for 6 to 8 h. The resultant smoke, therefore, contains very little pyrethrum but greater amounts of harmful gaseous and particulate air pollutants.[5]

Liu et al[6] reported that burning one MC for 8 h released the amount of particulate matter > 2.5 μm in mean aerodynamic diameter ($PM_{2.5}$) that was equivalent to burning 75 to 137 cigarettes and formaldehyde that was equivalent to burning 51 cigarettes. Studies show that the size of the particles in MC smoke are between 150 and 160 nm and are therefore capable of entering into the deep portions of the lung. These particles comprise toxic metals that include cadmium, lead,[7] and three-ring and four-ring polycyclic aromatic hydrocarbons, which are known to be carcinogenic.[8]

Household air pollution is now recognized as the leading risk factor for disability-adjusted life years in India and is the third leading cause in the world.[9] But so far, the emphasis has been largely on smoke produced during the burning of biomass fuels for cooking purposes. In this study, which was conducted in two phases, we aimed to measure the levels of indoor $PM_{2.5}$ and carbon monoxide (CO) during the burning of MCs with different ventilation patterns (window closed-door closed [WCDC], window open-door closed [WODC], and window open-door open [WODO]) in phase 1. In phase 2, which was a community-based survey, we investigated the different types of mosquito repellents used and the prevalence of respiratory symptoms in homes using different types of repellents.

Materials and Methods

Phase 1 was conducted in a room (5.7 × 3 × 2.4 m) that had one window (1.4 × 1.35 m) and one door (2.2 × 0.83 m) facing each other in the east-west direction. The three most commonly used brands of MCs in India were selected, including one that was marketed as a low-smoke coil. The chemical composition of the standard coils were *d*-trans allethrin (0.1%), wood flour (52.9%), coconut shell powder (35%), and starch binder (12%), whereas the low-smoke coil contained prallethrin (0.05%), potassium nitrate (5%) as a smoldering agent, guar gum (3%), starch (3%), emulsifier unit OX3 (0.5%), sodium benzoate (0.3%), clay dust (10%), calcite dust (10%), wood flour (15%), and charcoal (53.15%). Figure 1 shows a representative MC.

Each brand of MC was burned three times on three separate days in a randomized sequence and at the same location in the room to obtain the mean value of the different pollutants. After measuring the baseline $PM_{2.5}$ and CO for 20 min, each coil was burned for a total duration of 6 h, which included 2 h with WCDC, followed by 2 h with WODC, and finally 2 h with WODO. We followed the same sequence for all the coils, which were also burned at the same time of the day. Adequate washout was performed by keeping WODO until the $PM_{2.5}$ and CO values returned to background levels, to avoid any carryover effect from previous exposures.

Indoor $PM_{2.5}$ levels were measured using Thermo PDR 1200 (Thermo Electron Corporation), a light-scattering photometer that counts number of particles and converts them into mass, which is then expressed as μg/m^3. The inbuilt data logger recorded minute-by-minute levels of $PM_{2.5}$ over the entire duration of the study. Indoor levels of CO were measured using Easy Log data logger from Lascar Electronics. Both the instruments were calibrated regularly, and zeroing was done before and after each experiment.

The values recorded in both the instruments were exported to Microsoft Excel (Microsoft Corporation). The minute-by-minute $PM_{2.5}$ and CO levels were plotted against time. Statistical analysis was performed using SPSS, version 11.5 software (IBM Corporation). Differences in the mean ± SD for $PM_{2.5}$ and CO during WCDC, WODC, and WODO were compared using repeated measures of analysis of variance, and P values $<$ .05 were considered to be statistically significant.

Phase 2 of the study was a cross-sectional design, where three villages were randomly selected from 22 villages under the Vadu Health and Demographic Surveillance System region. Among the total of 4,851 registered homes in these three villages, 153 homes (51 from each village) were selected using a computer-generated randomization technique. We invited all individuals residing in these 153 households older than 18 years of age to participate in this study. This study was approved by the institutional review board.

Figure 1 – *A burning mosquito coil.*

Trained field workers visited all 153 randomly selected homes and explained to the eligible residents the study purpose and methodology in their local language. A verbal consent was obtained before they were enrolled into the study. Each individual was administered a questionnaire that captured the demographic details, type and frequency of mosquito repellents used, respiratory health indices, distance of the house from the highway, and other confounding factors such as use of biomass fuel, incense burning, active and passive tobacco smoking, size of the bedroom, and information on whether they kept the doors and windows open or closed when the mosquito repellents were used. The respiratory health questionnaire included questions from Burden of Obstructive Lung Disease (BOLD) and International Study for Asthma and Allergies in Children (ISAAC), which are standardized, validated questionnaire tools to assess the prevalence of COPD and asthma in community studies.

Data collected from the field were transcribed to Microsoft Excel using the double data entry method. Complete data were analyzed in SPSS 11.5 using simple descriptive analyses and represented as mean ± SD for continuous variables and frequency and percentages for categorical variables.

Results

Phase 1

The mean ± SD indoor levels of $PM_{2.5}$ (μg/m^3) at baseline, 2 h of WCDC, 2 h of WODC, and 2 h of WODO for the three sets of exposures for each of the three MCs are given in Table 1 and Figure 2. Similarly, levels for CO in parts per million (ppm) are given in Table 2 and Figure 3.

Phase 2

Of the 153 homes visited, 465 adult subjects consented to participate (213 men, 252 women; mean age ± SD, 35.8 ± 13.2 years). One hundred sixty-five (35.4%) used only MCs, 214 (46.0%) used only liquid mosquito repellents, and 85 (18.2%) participants used both MCs and liquid mosquito repellents. One study participant used no form of mosquito repellent. MCs (with or without other repellents) were used by 53.6% of the study population.

Among the MC users (MC and MC + liquid vaporizer), 68.4% used it every day and 26.8% used it < 3 d/wk. A total of 54.5% placed the MC in the corner of the room, 35.7% placed it under the bed, 4.2% placed it near the door, and 1.2% kept the MC near the window. During the burning of the MC, 63% kept both door(s) and window(s) closed, 21.8% kept either the door or window open, and 11.5% kept both the door and window open.

Eight out of 250 MC users were current smokers, and 15 had one or more smoker in the family. Two hundred forty-five (98%) MC users burned incense sticks regularly, and 51 individuals used biomass as cooking fuel with or without other fuels. One hundred sixty-one (64.9%) MC users lived > 500 m away from the highway, 58 (23.3%) lived < 100 m away, and 29 (11%) lived between 100 and 500 m away from the highway.

The mean bedroom volume of all the study homes was 23.5 m^3 (range, 8-60 m^3). Sixty-two homes had a volume < 20 m^3, and 91 homes had a volume > 20 m^3.

Compared with MC users, nonusers reported lower prevalence of asthma (3.6% vs 2.3%), allergic conjunctivitis (9.1% vs 6.5%), allergic rhinitis (9.7% vs 4.2%), eczema (1.2% vs 0.4%), and TB (1.21% vs 0.47%) (Table 3). Similarly, the symptoms of itchy nose, itchy eyes, runny nose, and blocked nose were higher among MC users compared with those who used liquid mosquito vaporizers (7.9% vs 5.2%, 15.2% vs 13.2%, 33.9% vs 29%, and 17.7% vs 15.2%, respectively). The prevalence of throat pain was, however, significantly higher among liquid mosquito repellent users (28.5% vs 15.2%; $P = .003$) (Table 3).

TABLE 1] $PM_{2.5}$ and CO Levels for Three Different Brands of MC With Window and Door Closed/Open for a Duration of 2 Hours Each

Coil	Background	WCDC	WODC	WODO
$PM_{2.5}$ levels, μg/m^3				
Mosquito coil A (n = 3)	72 ± 10	1,031 ± 582	510 ± 511	84 ± 35
Mosquito coil B (n = 3)	53 ± 10	848 ± 623	467 ± 514	61 ± 31
Mosquito coil C (low smoke) (n = 3)	74 ± 20	355 ± 179	170 ± 142	62 ± 10
CO levels, ppm				
Mosquito coil A (n = 3)	0.00 ± 0.00	5.20 ± 3.20	1.20 ± 2.38	0.00 ± 0.00
Mosquito coil B (n = 3)	0.06 ± 0.26	4.70 ± 2.94	1.50 ± 2.41	0.00 ± 0.09
Mosquito coil C (low smoke) (n = 3)	0.00 ± 0.00	6.50 ± 3.77	1.90 ± 2.58	0.00 ± 0.00

Data are presented as mean ± SD. MC = mosquito coil; $PM_{2.5}$ = particulate matter < 2.5 μm in mean aerodynamic diameter; ppm = parts per million; WCDC = window closed-door closed; WODC = window open-door closed; WODO = window open-door open.

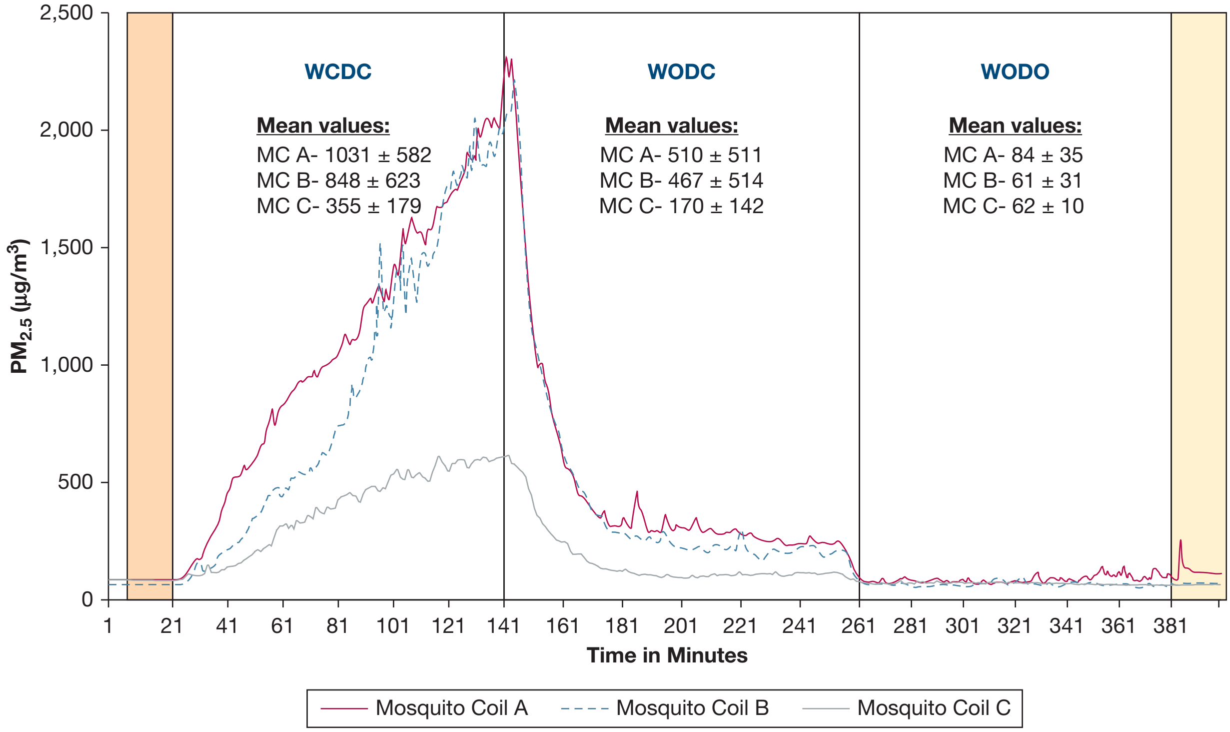

Figure 2 – *Mean Indoor $PM_{2.5}$ levels for three different brands of MC. (Values are means of three experiments with each coil.) MC = mosquito coil; $PM_{2.5}$ = particulate matter < 2.5 µm in mean aerodynamic diameter; WCDC = window closed-door closed; WODC = window open-door closed; WODO = window open-door open.*

MC users showed higher prevalence of breathlessness on exertion (37.7% vs 12.6%), need to walk slowly due to shortness of breath (22.1% vs 4.7%), cough for > 3 months but < 1 year (3.6% vs 0.5%), cough < 5 years (20.9% vs 5.6%), cough for > 5 years (1.8% vs 0.5%), wheeze in last 12 months (12.6% vs 6.1%), and wheeze in last 12 months associated with shortness of breath (14.5% vs 4.7%) compared with nonusers. These differences were not statistically significant. MC users living in homes < 20 m^3 volume had significantly higher prevalence rates of runny nose (50% vs 15%; $P < .001$), itchy nose (13% vs 2%; $P < .01$), blocked nose (30% vs 7%; $P < .001$), itchy eyes/ears (23% vs 7%; $P < .001$), itchy throat (41% vs 25%; $P < .001$), wheeze after a cold (16% vs 8%; $P < .05$), and shortness of breath (25% vs 11%; $P < .01$) (Fig 4).

We also measured peak expiratory flow rate (PEFR) in our study population, but there was no difference between users of MCs or liquid mosquito repellent vaporizer and those who used both (PEFR % predicted values, 85.4% vs 87.1% vs 87.1%, respectively; P = not significant). However, when we did more in-depth analysis, we did find a trend toward a difference in the proportion of people who used MCs and had PEFR values < 80% compared with those who used liquid mosquito repellent vaporizer and had PEFR values < 80% (38.60% vs 33.49%; $P = .07$).

Discussion

In this study, we report for the first time, to our knowledge, that indoor burning of MCs produces levels of $PM_{2.5}$ and CO that are much higher than those reported during the burning of biomass fuel for cooking purposes.[10] After opening the window, the levels of $PM_{2.5}$ and CO reduced dramatically but were still much higher than the safety limits prescribed by the World Health Organization. After keeping both the door and window open, the levels reduced to almost background levels, indicating a major impact of indoor ventilation patterns on MC smoke pollutants. In our community survey from rural India, 53.2% of participants used MCs either alone or along with a liquid vaporizer, and around 68% of people burned them daily. More than one-half of the people placed MCs in the room corners for an average duration of 6 to 8 h, and 63% of them kept both the door and windows closed. These observations are in accordance with those reported earlier[6,7,11,12] suggesting that a large number of people burn MCs at home to

TABLE 2] Descriptive Statistics for Demographic Variables

Statistics	Mosquito Coil Users	Liquid Vaporizer Users	Mosquito Coil + Vaporizer Liquid Users
Descriptive parameters of the study population, mean ± SD			
Age, y	35.8 ± 13.2	38.0 ± 14.2	35.2 ± 11.9
Height, cm	156.9 ± 8.5	158.3 ± 8.7	159.8 ± 8.7
Weight, kg	52.9 ± 10.4	58.5 ± 14.1	58.3 ± 12.8
Sex, M (F), %	41.2 (58.8)	48.2 (51.8)	48.24, (51.7)
Smoking status, %			
Current smoker	3.03	5.14	3.53
Never smoker	96.97	94.86	96.47
Incense use, %			
Incense sticks users	98.18	96.26	97.65
Cooking fuel, %			
LPG	64.1	66.5	81.2
Biomass	2.4	0.5	1.2
LPG + biomass	26.2	30.6	0
Others	7.3	2.4	17.6
House demographics, mean ± SD			
Area of house, m^2	401.2 ± 302.7	516.0 ± 292.5	552.8 ± 464.9
Volume of house, m^3	2,187.8 ± 774.7	2,226.2 ± 685.7	2,202.10 ± 961.6

LPG = liquid petroleum gas.

prevent mosquito bites and are exposed to extremely high levels of $PM_{2.5}$ and CO during the sleeping hours.

The low-smoke coil produced mean levels of $PM_{2.5}$ that were 2.4 to 2.9 times lower than the MC but were still 14 times higher than the indoor safety limits of $PM_{2.5}$ prescribed by the World Health Organization. The lower amounts of $PM_{2.5}$ are most likely because of the use of charcoal powder rather than coconut husk powder, and this also explains why low-smoke coils produced higher levels of CO (25.5% greater levels) than the standard MC.

We did not measure air exchange rates in the room when the MC was burned, but the dramatic reduction in indoor $PM_{2.5}$ and CO levels during opening of window and/or door suggests that indoor ventilation is a major determinant of the level of indoor air pollutants during the burning of MCs. Although our study shows that improving indoor ventilation significantly reduces the levels of MC-generated household air pollution, this would likely increase the risk of mosquitoes entering the room.

There are only a few published studies that have examined the adverse health effects of MC smoke, and these have reported increased prevalence of respiratory symptoms,[6,11,13] asthma,[6,13] lung cancer,[6,12] and hypersensitivity pneumonitis.[14] In our rural village study, use of MCs was associated with a higher numerical prevalence of runny nose, itchy nose, blocked nose, and itchy eyes, whereas throat pain was reported to be more common among liquid vaporizers. Similarly, the prevalence rates of self-reported asthma, allergic conjunctivitis, allergic rhinitis, and eczema were higher among those using MCs. These effects were more pronounced among those living in smaller homes. Although we observed higher prevalence rates of respiratory symptoms and self-reported respiratory and allergic diseases among those using MCs, the values did not reach statistical significance. This could be because of a relatively small sample size studied (250 MC users vs 214 liquid mosquito repellent users) or due to other potential confounding factors that may have weakened this association. For example, burning of incense sticks was performed by 97.2% of the study participants for an average of 28 min/d for > 26 d/mo. Similarly, > 28% of homes used biomass fuel for cooking, and 45% of the participants lived < 500 m from the main highway. More studies are now urgently required to study the association between MC smoke pollution and adverse health effects.

Our study has several limitations. We tested only the three most common brands of MCs available in India, which may not be representative of MC used in other countries. Although we tested the indoor levels of $PM_{2.5}$ and CO for each brand of MC on three separate days, it

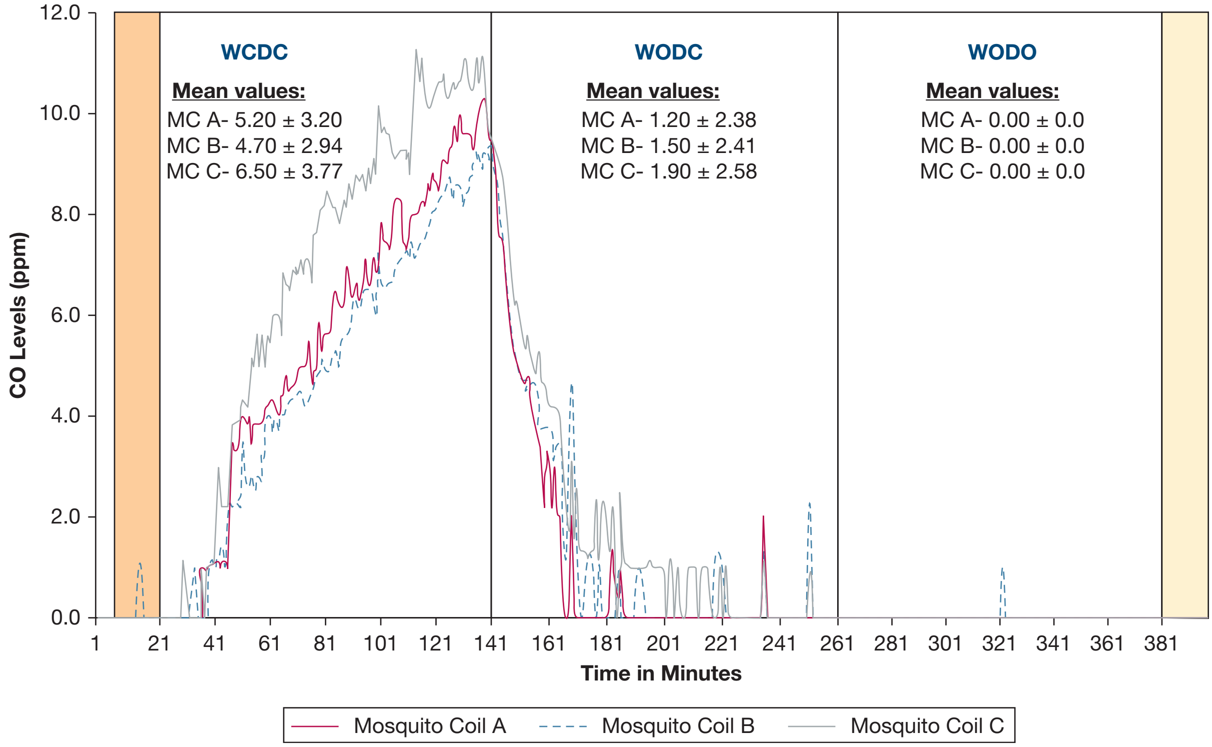

Figure 3 – *Mean CO (ppm) levels for three different brands of MC. (Values are means of three experiments with each coil). CO = carbon monoxide; ppm = parts per million. See* Figure 1 *legend for expansion of other abbreviations.*

is likely that the levels may vary with both outdoor and indoor wind patterns and temperatures. The community-based observational study was conducted in a relatively small population and was likely confounded by the burning of incense sticks and use of biomass fuel for cooking purposes. Despite these limitations, the observations made in this study highlight a hitherto little-appreciated fact that burning of a MC produces very high levels of indoor $PM_{2.5}$ and CO, which is likely to be a major public health issue.

TABLE 3] Prevalence of Self-Reported Respiratory and Allergic Diseases and Respiratory Symptoms Among Individuals Using Different Types of Mosquito Repellents

Disease or Symptom	Liquid Mosquito Repellent Users (n = 214)	Mosquito Coil Users (n = 165)	Liquid Mosquito Repellent + Mosquito Coil Users (n = 85)
Respiratory and allergic diseases			
Asthma	2.34	3.64	4.71
Allergic conjunctivitis	6.54	9.09	9.41
Allergic rhinitis	4.21	9.70	3.53
Eczema	0.47	1.21	2.35
TB	0.47	1.21	1.18
Self-reported respiratory and allergic symptoms			
Runny nose	28.9	33.9	35.7
Itchy nose	5.1	7.9	13.1
Blocked nose	15.1	17.6	21.1
Itchy eyes/ears	13.1	15.2	17.6
Throat pain	28.5	15.1	21.4
Itchy throat	27.8	26.8	29.7

Data are presented as %.

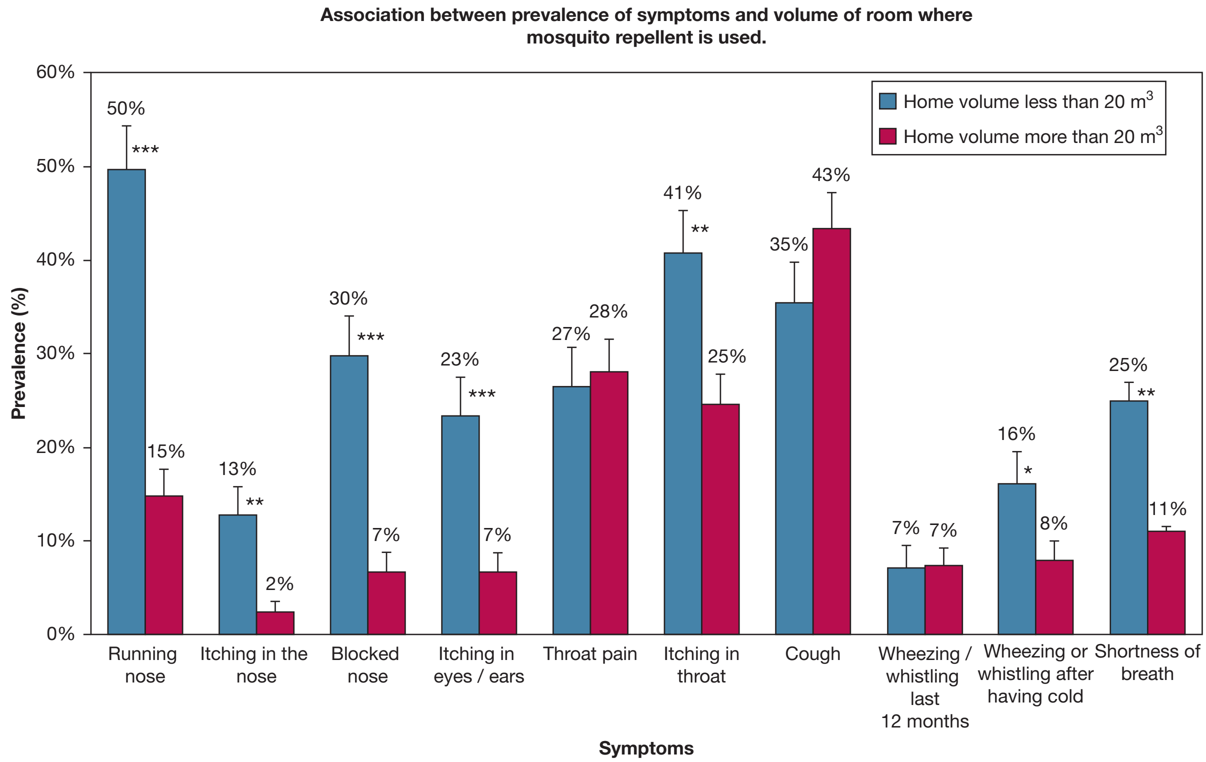

Figure 4 – *Prevalence of symptoms among participants living in homes < 20 m^3 volume and vs > 20 m^3 where mosquito coils are used. (*P < .05; ** P < .01 and *** P < .001)*

An estimated 2 billion people across the globe use MCs with little awareness about the harmful levels of air pollutants that they inhale during the sleeping hours at night. The results of our study should raise an alarm about the potential adverse health effects that may be caused by the burning of MCs. Apart from creating awareness among lay people, public health policy makers, health-care providers, and scientists, more studies are urgently required to assess the true burden and adverse effects caused by the burning of MCs.

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Author contributions: S. S. had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis, including and especially any adverse effects. D. S., S. B., and S. S. contributed to conception and design of the study; D. S. and S. S. contributed to planning and executing the study; S. L., V. M., and S. B. contributed to equipment; D. S., S. L., J. L., S. M., and S. S. contributed to questionnaire design and testing; D. S., J. L., and S. J. contributed to data collection and coordination of field work; S. M., D. S., and S. S. contributed to analysis; D. S., S. L., V. M., J. L., S. M., S. J., S. B., S. S contributed to writing and revision of the paper.

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