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Indoor Fine Particle (PM_{2.5}) Pollution Exposure due to Secondhand Smoke in Selected Public Places of Sri Lanka

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Abstract

Background—Secondhand smoke accounts for a considerable proportion of deaths due to tobacco smoke. Although the existing laws ban indoor smoking in public places in Sri Lanka, the level of compliance is unknown.

Methods—Fine particulate matter (PM_{2.5}) levels in 20 public places in Colombo, Sri Lanka were measured by a PM monitor (Model AM510 - SIDEPAK Personal Aerosol Monitor). Different types of businesses (restaurants, bars, cafés and entertainment venues) were selected by purposive sampling. Only the places where smoking was permitted were considered.

Results—The average indoor PM_{2.5} ranged from 33 to 299 µg/m³. The average outdoor PM_{2.5} ranged from 18 to 83 µg/m³. The indoor to outdoor PM_{2.5} ratio ranged from 1.05 to 14.93. In all venues, indoor PM_{2.5} levels were higher than the Sri Lankan ambient PM_{2.5} standard of 50 µg/m³. All indoor locations had higher PM_{2.5} levels as compared to their immediate outdoor surroundings.

Conclusion—The study highlights the importance of improving ventilation and enforcing laws to stop smoking in public places.

Keywords

tobacco; smoking; Sri Lanka; public; secondhand smoke

INTRODUCTION

According to the World Health Organization (WHO), approximately five million deaths per year worldwide may be attributed to tobacco use, and the number is expected to exceed eight million per year by 2030 (WHO, 2008). A large proportion of deaths may be attributable to secondhand smoke (SHS). The WHO estimates that 9% to 13% of all cancer

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cases may be attributed to SHS in a non-smoking population. They recommend that countries enact and enforce legislation for all indoor work places and public places to be 100% smoke-free to counter the harmful effects of SHS. In reality, non-smokers may be exposed to tobacco smoke at various public places, even though legislation is enacted to ban smoking in indoor public places in some countries.

SHS is generated by the combustion of tobacco products. SHS is a complex mixture of over 4,000 compounds which include over 50 known or suspected human carcinogens (Lee et al., 2007; WHO, 2000). Even brief exposures can trigger respiratory symptoms, including cough, phlegm, wheezing and breathlessness. There are sufficient data to suggest that children exposed to SHS are at an increased risk for sudden infant death syndrome, middle ear problems, impaired lung functions, and lower respiratory illnesses in childhood (USDHHS, 2006; WHO, 2008; Chen et al., 2009). Adult exposure to SHS has adverse effects on coronary heart disease, nasal irritation, respiratory effects including lung cancer, and reproductive effects in women including low birth weight (WHO, 2008; USDHHS, 2006; Jadsri and Jadsri, 1995). The pooled evidence indicates a 20% to 30% increase in the risk of lung cancer from SHS exposure associated with living with a smoker (USDHHS, 2006).

PM_{2.5} has been used as a surrogate for SHS exposure in several studies. A study in Pakistan reported an average indoor PM_{2.5} levels of 138.8 µg/m³ with the indoor/outdoor ratio ranged from 0.97 to 10.2 in enclosed smoking public venues (n = 20) (i.e. restaurants, cafes, snooker/billiard clubs and gaming zones) (Nafees et al., 2011). Another study from Ghana found that median PM_{2.5} of same type of venues (n = 75) was 553 µg/m³ (Agbenyikey et al., 2011). Several other studies have compared SHS levels before and after the smoking-ban of public venues by monitoring the PM_{2.5} (Gotz et al., 2008; Lee et al., 2007; Gee et al., 2006). Repace et al (2006) found a reduction of PM_{2.5} levels from 179 µg/m³ to 7.7 µg/m³ in bars in Boston, United States (US), following the enactment of indoor smoking laws.

Many countries have enacted laws to restrict occupational and public exposures to SHS. The National Authority on Tobacco and Alcohol Act (No. 27 of 2006) of Sri Lanka states that, “No person shall smoke or allow any person to smoke any tobacco product within any enclosed public place; any person who being the owner, occupier, proprietor, manager, trustee or person in charge of any enclosed public place shall ensure that no person smokes any tobacco product within any such enclosed public place.” However, the Act permits any hotel, guest house or lodge having thirty rooms or more, and any restaurant or club having a seating capacity of a minimum of thirty persons to have within its premises an enclosed space or enclosed area as the case may be, set aside exclusively for smoking. Such areas shall be provided with adequate ventilation and shall conform to the prescribed air quality standards (NATA, 2006). The 2007 Global Youth Tobacco Survey (GYTS) of 2007 found that 65.9% Sri Lankan youth (13–15 years old) are exposed to SHS in public places (Gunasekara et al., 2008). Based on the 2005 data, WHO reported the prevalence of current tobacco use among Sri Lankan adult (≥ 15 years) males and females were 30.2% and 2.6%, respectively (WHO, 2009).

The purpose of our study was to assess PM_{2.5} levels as an indicator of SHS in selected public places in Colombo, Sri Lanka, where smoking is permitted.

METHODS

Study design and setting

We conducted a descriptive cross-sectional study sampling 20 enclosed public places during January to March 2009. We classified public places as spaces which could be visited without

permission. We did not inform the management of the visit or that measurements would be taken beforehand. Only the places where smoking was permitted were considered. Places that had a separate cubicle/location for smoking, as permitted by law, were excluded. We selected four different types of public places: 1) restaurants (places where meals are prepared, served and eaten and alcohol is served on request); 2) bars including buildings or a room in a hotel in which both alcoholic and other drinks are primarily served; 3) cafés including small restaurants serving inexpensive meals and drinks but do not serve alcohol; and 4) pool parlors, including entertainment venues that serve alcohol and offer various games, mainly pool and billiards.

Monitoring methods

We measured the PM_{2.5} levels using a PM monitor (Model AM510 - SIDEPAK Personal Aerosol Monitor). This monitor has been used in similar studies of SHS exposure (Jones et al., 2006, Lee et al., 2007). The SIDEPAK Personal Aerosol Monitor uses a built-in sampling pump that draws air through the device, and the PM in the air scatters light emitted from a laser. Based on the scattering of light and application of an impactor to remove particles larger than 2.5 micrometres, the device determines the real-time concentration of PM_{2.5}. The PM monitor was calibrated for tobacco-related PM. Based on the calibration experiment against gravimetric measurement, the measured value was corrected by a conversion factor of 0.295 (Lee et al., 2008). The instrument was zero-calibrated prior to measurements on a daily basis by attaching a zero-calibration filter according to the manufacturer's specifications. The equipment was set to a one-minute log interval.

We visited each venue for a minimum of 40 minutes. The PM monitor was concealed in a backpack and was operated continuously throughout the visit. We measured the outdoor air quality of the venue for at least 10 minutes before and after entering the venue walking around a 5m area outside the venue. If the venue was in close proximity to an arterial road with heavy traffic (main entrance located < 50m) or a traffic light (main entrance located > 100m), we measured the outdoor air quality for at least 20 minutes, as the PM_{2.5} concentrations were likely to be unstable. We selected a central location for the measurements away from the service entrance leading to the kitchen areas. The concealed PM monitor was kept about three feet from the floor. The number of people inside the venue and the number of lit cigarettes were counted every 10 minutes. Measurements were completed without being noticed ensuring that no changes in behaviour occurred. Relevant information (date and time, estimated room/area dimensions, number of persons present, number of lit cigarettes/cigars, description of the venue and maximum occupancy) was noted during the measurements on a pre-designed data sheet. Measurements were conducted during busy business hours (i.e. between 12.00 hrs to 14.00 hrs and 17.00 hrs to 20.00 hrs). The sampling time was pre-scheduled and measurements were continued irrespective of the number of smokers and visitors. Data were collected by a single investigator throughout the study accompanied by an assistant to facilitate documentation. The study was reviewed and approved by the Ethics Committee of the Faculty of Medicine, University of Kelaniya, Sri Lanka.

Analysis

We calculated the means of indoor and outdoor PM_{2.5} measurements for each venue. The first and last minute of logged data were removed, because they were averaged with outdoor and entry way air. The remaining data points were averaged to provide an average indoor PM_{2.5} concentration. The outside PM_{2.5} concentration was calculated using the data points of outdoor measurements of the venue which were collected before entering the venue and after completing the indoor measurement. We calculated the smoking density (the number of burning cigarettes for 100 cubic meters of space (bcs/m³)) for each venue by using the

average number of burning cigarettes during the measurement period and the approximate size of the restaurant. The mean and median of each measurement for each type of venue was calculated. We used Spearman's rank correlation coefficient to determine the association of indoor PM_{2.5} concentration with smoking density and outdoor PM_{2.5} concentration.

RESULTS

We measured the indoor air quality in six restaurants, six bars, four cafés and four entertainment venues. Table 1 provides a description of each venue including the maximum occupancy, size and approximate distance to a main road. Table 2 shows the descriptive statistics of outdoor and indoor PM_{2.5} concentrations, standard deviation (SD), inter-quartile range of each concentration, indoor to outdoor ratio (I/O ratio) and smoking density of each venue. All 20 venues had higher indoor PM_{2.5} levels than their immediate outdoors. The indoor PM_{2.5} levels ranged from 33 to 299 µg/m³ and the outdoor PM_{2.5} levels ranged from 18 to 83 µg/m³. The I/O ratio ranged from 1.05 to 14.93. Table 3 shows the outdoor and indoor PM_{2.5} concentrations and smoking density by type and size of venue. The average indoor PM_{2.5} level was 124.9 ± 81.0 µg/m³. The highest mean indoor PM_{2.5} level was reported from pool parlors with a mean of 183.5 µg/m³ (median, 205.0 µg/m³) and the lowest from cafés with a mean of 68.3 µg/m³ (median, 64.0 µg/m³).

Spearman's rank correlation coefficient (ρ) of indoor and outdoor PM_{2.5} concentrations was 0.44 ($p = 0.05$). The indoor PM_{2.5} concentration and smoking density were not significantly correlated ($\rho = 0.33$; $p = 0.15$) (Figure 1). When smoking density was classified into three groups, <0.5 bcs/100m³, 0.5–1 bcs/100 m³ and >1 bcs/100m³, the mean indoor PM_{2.5} concentrations in these areas were 71 µg/m³, 119 µg/m³ and 148 µg/m³, respectively.

DISCUSSION

We found high levels of PM_{2.5} in our sample of public places, as compared to their immediate outdoor environments. The highest mean indoor PM_{2.5} level was recorded in pool parlors. PM_{2.5} concentration is a widely accepted indicator to assess indoor air quality and is an accepted marker of SHS (Valente et al., 2007). Few studies conducted in developed countries have reported SHS smoke exposures in such venues (Jones et al., 2006, Valente et al., 2007, Gee et al., 2006, Lee et al., 2007).

Indoor PM_{2.5} may be from outdoor sources which have entered indoors, smoke from kitchens using biomass fuels, or smoke from burning cigarettes. None of the study venues had a kitchen directly opening into the area where the measurements were taken. In this study, fine particle release from burning cigarettes was the most likely source of the high PM_{2.5} concentrations. Precautions were taken to avoid direct contact with active smoking during monitoring to ensure representative samples of mixed concentrations.

The Sri Lankan government has taken several initiatives within the last few years to reduce the smoking prevalence, as well as SHS, with high level political patronage. Some of the initiatives taken include the enactment of the National Authority on Tobacco and Alcohol Act (No. 27 of 2006) by the Ministry of Health, the increase of taxes on cigarettes and implementing awareness programs regarding the adverse effects of cigarette smoking. These activities may have contributed to the decline in the smoking prevalence in Sri Lanka over the last decade. By law, smoking is prohibited in places where non-smokers would be exposed to tobacco smoke, including restaurants, bars, cafés, and entertainment venues (NATA, 2006). A “public place” is defined in the act as “any place to which the public have

access, whether as of right or otherwise. However, the places we selected in the present study allowed smoking openly, irrespective of existing laws.

In other countries, the availability of separate cubicles has led to a reduction of SHS exposure among non-smokers. Carrington et al (Carrington et al., 2003) found that the provision of non-smoking areas significantly reduced median concentrations of respirable suspended particles and nicotine by 18% and 68%, respectively, in the non-smoking section as compared to smoking sections, in pubs located in Greater Manchester, United Kingdom (UK). Average PM_{2.5} level found in our study was 3 to 11 fold higher than the post legislation levels reported in same type of public venues in other countries. For example Gotz, et al. (2008) reported 11.0 µg/m³ in UK; Lee et al. (2007, 2008) reported 18.0 µg/m³ in Georgetown and 18.0 µg/m³ in Lexington, Kentucky; Valente et al (2006) reported 38.2 µg/m³ in Italy (Table 4). However, some of the studies conducted in the pre-legislation period have higher values than that found in the present study. The median PM_{2.5} level in German venues (n = 95) were 260 µg/m³ (Schneider et al, 2008); average PM_{2.5} level in UK venues was (n = 49) 217 µg/m³ (Gotz et al. 2008); average PM_{2.5} level in Boston venues (n = 6) was 179 µg/m³ (Repace et al, 2006).

While there are no occupational exposure limits or indoor air quality limits for SHS or PM_{2.5}, studies in other countries (Semple et al., 2007, Edwards et al., 2006, Lee et al., 2007) have compared air quality measurements of PM_{2.5} levels recommended by the US Environmental Protection Agency's (US EPA) National Ambient Air Quality Standards (NAAQS) (35 µg/m³ for 24-hours). Although these limits are for outdoor particulate pollution based on a 24-hour exposure, our results indicate the potentially hazardous nature of the indoor air quality measurements in the selected venues we studied. The recently enacted Sri Lankan ambient air quality standard for 24-hour PM_{2.5} levels is 50 µg/m³, the same as the interim target-2 of the WHO guidelines (WHO, 2005). The WHO recommends the same guideline (25 µg/m³) for indoor environments. Although our sample measurements were taken for only 40 minutes in each location, the high mean values of 124.9 µg/m³ (± 81.0) suggest a high exposure risk for non-smokers especially employees. The standards quoted are for PM_{2.5} levels and there is no safe level for SHS *per se* (WHO, 2007).

Indoor exposures to air pollutants are a result of complex interactions between the structure, building systems, indoor source strength, removal and deposition rate within the structure, indoor mixing and chemical reactions, furnishings, the outdoor environment, and the practices and behaviours of the inhabitants (Mitchell et al., 2007). Building ventilation systems greatly affect the removal rate of pollutants. When the windows are open and the wind-speed is moderate or high, indoor concentrations of air pollutants may be similar to outdoor concentrations. In contrast, even with relatively modest emissions, high PM_{2.5} concentrations may result inside a closed indoor environment (WHO, 1999).

In our study, the smoking density was not significantly correlated with indoor fine particle concentrations. Nafees et al. (2011) reported similar findings (Spearman correlation coefficient of 0.113) in a study conducted in Karachi, Pakistan. This may be due to different passive ventilation mechanisms in each venue which may be dependent on the size and number of windows and doors, and whether they are opened or closed. Air conditioned venues (restaurants 1, 2, and 3; bars 3 and 4) had higher I/O ratio despite most having lower smoking densities. Further, most of the venues which had high I/O had less number of opened windows compared to the size of the venue. As an example, high indoor PM_{2.5} concentration and highest I/O ratio of pool parlour – 4 may be due to inadequate ventilation as it had only one opened window during the monitoring period. The correlation between indoor and outdoor PM_{2.5} was higher than the indoor PM_{2.5} and smoking density, suggesting that the outdoor PM_{2.5} levels may have contributed to indoor PM_{2.5} levels.

Outdoor PM_{2.5} levels were ranged from 18 to 83 µg/m³ among 20 venues, and this may have varying influence on indoor PM_{2.5} levels based on the other contributing factors such as number of opened windows (Martuzevicius et al., 2008).

We measured air quality for only 40 minutes and smoking behaviours prior to the sampling period may have influenced our recordings. Lack of any mechanical ventilation system in any of these venues may have contributed to the accumulation of fine particles released from smoking prior to our recordings.

We strongly recommend a more vigilant enforcement of the law and the maintenance of an acceptable air exchange rate that could be achieved through the enforcement of laws and regulations related to building construction. Establishment of mechanical ventilation systems may be another option for achieving optimal air exchange rates. In restaurants where smoking is permitted, separate smoking areas may be constructed according to government specifications (NATA, 2006). The construction of designated smoking rooms are not recommended by the WHO due to several reasons such as the challenges of insulating the rooms, the expense of installation and maintenance of such facilities, lack of quality control, concentrated SHS exposures for smokers and workers, and doors opening in to non-smoking areas (WHO, 2007).

The unavailability of certain data posed limitations in our study. PM_{2.5} concentration data for indoor public places prior to enforcement of laws in Sri Lanka are not available. Therefore, we compared indoor air quality of public places that permit smoking with the immediate outdoor air quality of the venue as a proxy for air quality in indoor public places that do not permit smoking. Further we could not calculate the exact air exchange rate. However, we collected information on other attributes of venues that allowed us to make some reasonable assumptions.

CONCLUSIONS

Public places that allow smoking in Sri Lanka have high PM_{2.5} concentrations, comparable to the levels found in similar venues in other countries prior to enforcement of anti-smoking laws. Although laws exist for banning indoor smoke in Sri Lanka, we found that some public places still allow smoking exposing their clients and employees to high level of SHS. We recommend more stringent enforcement of anti-smoking laws in public venues in Sri Lanka to mitigate exposure to SHS.

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Figure 1.
Indoor PM_{2.5} concentration by smoking density 155 × 103mm (300 × 300 DPI)

Table I
Description of selected venues monitored for secondhand smoke levels in Colombo, Sri Lanka

Type of venue	Max. occupancy ^a	Distance to road	Size (m ³)	Fans ^c	Floorlevel	Window/AC ^d	Remarks ^e
Restaurant							
1	28	70	120	3	2	3	Kitchen was in the third floor
2	40	60	212	8	2	6	Kitchen was in the first floor
3	65	40	720	3	3	AC	Kitchen was in the same floor and was connected to the serving area by a passage of approximately 6 m.
4	32	70	160	4	1	1	Lower than ground level; window was half of total size of one side wall; Kitchen was adjacent, but separated by glasses; Kitchen door opens to the adjacent public area next to the monitoring area.
5	44	50	199	-	1	AC	Kitchen was approximately 4 m away from the public area and connected by a passageway.
6	46	50	210	2	1	AC	Kitchen was in a separate building, 5m away from the public area.
Bar							
1	40	60	80	6	1	5	Kitchen was in a separate building, lower ground level than the public area
2	50	70	255	8	1	3	Kitchen was connected to the public area by a passageway of 4m.
3	50	60	262	-	2	AC	Kitchen was in the third floor
4	48	50	125	6	2	-	No directly opened windows; kitchen not directly opened to the public area.
5	32	40	70	4	1	1	Window was larger than half of one sidewall; kitchen was in the adjacent building separated only by 1m; a grill at the front entrance.
6	36	70	105	-	1	AC	Kitchen was in the second floor.
Café							
1	16	130	875	1	1	-	No open windows; opened door; no kitchen; only electric-operated water boilers
2	28	200	37	-	1	1	Window was quarter the size of one side wall; a electric-operated water boilers only
3	20	70	60	-	2	4	Kitchen was in first floor; a grill was at the entrance of the first floor.
4	40	50	99	7	2	-	No windows were open; kitchen was in the first floor; door was always open.
Pool parlor							
1	28	20	124	3	1	3	Kitchen was not directly open to the public area.
2	36	10	104	2	1	-	No directly open windows; door directly opened to a major road; kitchen was separated by a passage of 7m.
3	54	90	240	8	2	7	Kitchen was in first floor.
4	28	300	270	5	1	1	Door was always open; kitchen was in a separate building 2m from the venue.

^aBased on the number of chairs available.

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^b Less than 100m from a junction with traffic light.

^c Only working fans while the monitoring was in progress.

^d AC = Air conditioned

^e Kitchen floor level is mentioned if it is different from the public area; only the open windows during the measurement period is counted; status of the door is mentioned if only it is opened.

Table II
Descriptive statistics of indoor and outdoor PM_{2.5} concentrations and smoking density by venue in Colombo, Sri Lanka

Type of venue	Indoor PM _{2.5} (µg/m ³)		Outdoor PM _{2.5} (µg/m ³)		Indoor/Outdoor ratio	Mean smoking density(bcs/100m ³)
	Mean (SD)	Median (IQR (25% – 75%))	Mean (SD)	Median (IQR (25% – 75%))		
Restaurant						
1	45 (16)	42(33 – 48)	31 (11)	26(23–28)	1.45	0.94
2	45 (17)	43(33 – 49)	29 (11)	24(23–28)	1.55	1.25
3	61 (12)	58(52 – 63)	28 (5)	30(26–32)	2.13	0.10
4	85 (19)	85(78 – 19)	36 (21)	34(26–44)	2.38	1.00
5	173(25)	41(163–113)	56 (31)	49(38–68)	3.06	0.50
6	114 (19)	124(97 – 126)	42 (13)	41(33–51)	2.71	0.76
Bar						
1	181 (79)	196(85 – 217)	50 (18)	42(35–69)	3.64	4.25
2	184 (79)	174(106 – 227)	38 (11)	38(30–46)	4.82	0.94
3	91 (23)	87(70 – 105)	43 (8)	43(37–47)	2.10	0.31
4	181 (52)	178(122–201)	38 (30)	36(29–44)	4.76	2.24
5	33 (10)	30(25 – 37)	31 (13)	27(20–36)	1.05	0.57
6	299 (57)	292(242 – 331)	37 (26)	31(26–39)	8.15	1.52
Café						
1	55 (56)	37(32 – 49)	27 (12)	23(18–32)	2.06	0.91
2	42 (17)	39(31 – 54)	28 (5)	30(24–32)	1.49	1.60
3	73 (40)	66(55 – 110)	41 (42)	39(35–45)	1.76	1.33
4	103 (29)	109(92 – 129)	35 (36)	32(25–48)	2.94	1.80
Pool parlor						
1	246 (89)	229(129 – 264)	83 (17)	84(65–91)	2.98	2.00
2	164 (39)	150(135 – 191)	59 (11)	60(52–63)	2.79	1.67
3	61 (27)	54(44 – 64)	45 (30)	36(26–47)	1.36	0.42
4	263 (136)	243(184 – 327)	18 (3)	17(16–20)	14.93	0.81

Table III
Indoor and outdoor PM_{2.5} concentrations and smoking density by type and size of venue in Colombo, Sri Lanka

	Indoor PM _{2.5} (µg/m ³)		Outdoor PM _{2.5} (µg/m ³)		Indoor/ Outdoor ratio (median)	Smoking density (median) (#bcs/100m ³)
	Mean ±SD	Median (IQR)	Mean ± SD	Median (IQR)		
Venue type						
Restaurants	87 (50)	73.0 (45–129)	37 (11)	33 (29–45)	2.2	0.8
Bars	161 (91)	181 (76–213)	39 (6)	38 (35–45)	4.2	1.2
Cafés	68 (26)	64 (45–95)	33 (6)	31 (27–39)	1.9	1.5
Pool parlors	183 (92)	205.0 (87–259)	51 (27)	52 (25–77)	2.8	1.2
Size of the venue						
Small	81(54)	64 (40–122)	35 (9)	33 (28–43)	1.9	1.5
Medium	170 (87)	173 (85–246)	49 (18)	38 (36–59)	3.0	1.5
Large	117 (79)	91 (61–184)	35 (10)	38 (28–43)	2.1	0.8

SD = Standard deviation

IQR = Inter quartile range

bcs = Burning cigarettes

Table IV

Results of secondhand smoke exposure monitoring studies in other countries; before and after smoking bans in public venues

Study area/Country Authors	Average PM _{2.5} concentrations	
	Pre legislature (µg/m ³)	Post legislature (µg/m ³)
UK [Gotz, et al. 2008]	217.0	11.0
Georgetown, Kentucky, US [Lee, et al. 2007]	84.0	18.0
Lexington, Kentucky, US [Lee, et al. 2008]	199.0	18.0
Italy [Valente, et al. 2007]	119.3	38.2
UK [Gee, et al. 2006]	114.5	76.2
Colombo, Sri Lanka Present study ^a	-	124.9

^aData from indoor public places that permit smoking.