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PM_{2.5} as a marker of exposure to tobacco smoke and other sources of particulate matter in Cairo, Egypt

C. A. Loffredo*, Y. Tang*, M. Momen†, K. Makambi*, G. N. Radwan‡, and A. Aboul-Foutoh†

*Georgetown University, Washington, District of Columbia, USA

†Ain Shams University, Cairo, Egypt

‡Cairo University, Cairo, Egypt

Summary

Setting—Cairo and Giza governorates of Egypt.

Background—Particulate matter under 2.5 µm in diameter (PM_{2.5}) arises from diverse sources, including tobacco smoke from cigarettes and waterpipes, and is recognized as a cause of acute and chronic morbidity and mortality.

Objective—To measure PM_{2.5} in workplaces with different intensities of smoking and varying levels of smoking restrictions.

Design—We conducted an air sampling study to measure PM_{2.5} levels in a convenience sample of indoor and outdoor venues in 2005–2006.

Results—Using a calibrated SidePak instrument, 3295 individual measurements were collected at 96 venues. Compared to indoor venues where tobacco smoking was banned (PM_{2.5} levels 72–81 µg/m³), places offering waterpipes to patrons of cafes (478 µg/m³) and Ramadan tents (612 µg/m³) had much higher concentrations, as did venues such as public buildings with poor enforcement of smoking restrictions (range 171–704 µg/m³). Both the number of waterpipe smokers and the number of cigarette smokers observed at each venue contributed significantly to the overall burden of PM_{2.5}.

Conclusion—Such data will support smoke-free policies and programs aimed specifically at reducing environmental tobacco exposure and improving air quality in general, and will provide a baseline for monitoring the impact of tobacco control policies.

Keywords

particulate matter; indoor air quality; smoking

ATMOSPHERIC PARTICULATE MATTER with diameter 2.5 µm (PM_{2.5}) is generated from anthropogenic sources such as vehicle exhaust and tobacco smoke, and is composed of diverse compounds and elements, including organic matter, sulfates, ammonium, nitrates,

Correspondence to: Christopher Loffredo, Georgetown University, 3970 Reservoir Rd NW, Washington, DC 20057, USA. Fax: (+1) 202 687 0313. cal9@georgetown.edu.

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and various metals (e.g., copper, chromium, manganese, arsenic, lead and zinc).^{1,2} The main route of human exposure results in absorption into the bloodstream through the respiratory tract. Studies show that variations in the level of PM_{2.5} in air is associated with changes in the incidence of all-cause mortality^{3,4} and with cause-specific hospital admissions,⁵ especially for cardiovascular and respiratory diseases.⁶ PM_{2.5} is a major component of both cigarette smoke and environmental tobacco smoke (ETS), both of which are associated with cancer and other chronic diseases. The US Environmental Protection Agency cited over 80 epidemiologic studies in creating an initial particulate air pollution standard in 1997 to protect public health, and more recently updated the current standards to 12 µg/m³ as the average annual level of PM_{2.5} exposure, with 35 µg/m³ as the upper limit for 24-h exposure.^{7,8}

Although PM_{2.5} levels have been well characterized in relation to cigarette smoking, relatively little is known about the contribution of waterpipe (or *hookah*) smoking to PM_{2.5}, particularly in countries in North Africa and the Middle East, where waterpipe smoking represents a major form of tobacco use.⁹ Exposure to ETS from waterpipes, which are typically smoked in social settings, including cafes, bars, and restaurants, may be of particular concern for workers in such establishments, who often have low levels of protection due to inadequate smoking regulations in some countries.^{10–16} The World Health Organization's Framework Convention on Tobacco Control calls on governments to 'protect all persons from exposure to tobacco smoke', rather than just specific populations such as children or pregnant women. This protection should be extended, according to Article 8 to, 'indoor workplaces, public transport, indoor public places and...other public places'.¹⁷

Limited laboratory-based testing suggests that the levels of particulate matter (PM) released from waterpipes under controlled conditions are comparable to those from cigarettes; in one such experimental protocol, a waterpipe smoking session of 30 min generated PM emissions similar in magnitude to a single cigarette smoked for 10 min.¹⁸ In contrast, data reporting measurements of PM_{2.5} under natural exposure conditions of waterpipe smoking are scanty, and the contribution of such emissions to the overall societal burden of PM_{2.5} has yet to be established.

The purpose of our study was to measure PM_{2.5} in a sample of workplaces in Cairo, Egypt, characterized by different intensities of waterpipe smoking and varying levels of indoor smoking restrictions. Such data will support more effective smoke-free policies and programs aimed at reducing ETS exposure, and will provide a baseline for monitoring the impact of tobacco control policies.

Methods

The study was approved by the Institutional Review Boards of the University of Maryland (Baltimore, MD, USA), Ain Shams University (Cairo), and the Ministry of Health in Egypt (Cairo, Egypt).

Venues sampled

A convenience sample of hospitality settings (waterpipe cafes, restaurants, and Ramadan tents) was selected for PM_{2.5} monitoring between 12 October 2005 and 31 January 2006, in the Cairo and Giza governorates of Egypt. Waterpipe cafes are establishments offering food, drinks, and waterpipes to patrons, while Ramadan tents are similar places where people gather in the evenings after daily fasting during the month of Ramadan. PM_{2.5} levels were also examined during the same time period for a cross-section of other public places with varying degrees of indoor air restrictions: Cairo International Airport, a municipal court building, a faculty office building at Ain Shams University, and government offices, where tobacco smoking is officially restricted but not well enforced; in transport vehicles such as buses and taxis, where tobacco smoking is restricted but enforcement is at the driver's discretion; in the open air of the center of a semi-rural village within Giza governorate; and sidewalks along major streets as well as in the center of the crosswalk. A mosque and our Cairo study office (Egyptian Smoking Prevention Research Initiative [ESPRI]) were also included in the air sampling protocol, as they were among the only places in the regions where tobacco smoking was absolutely not allowed. The hospitality settings were sampled between 6 pm and 3 am; sampling was carried out between 8 am and 2 pm in all other settings.

Measurements

Each sampling site was tested for a minimum of 60 min. A TSI SidePak AM510 Personal Aerosol Monitor (TSI Inc, St Paul, MN, USA) was used to sample and record the levels of suspended particles in the air. Sampling was performed discreetly to avoid disturbing the occupants' normal behavior, and the device was concealed in a backpack, with the inlet tube protruding just far enough to allow air sampling. The SidePak uses a built-in sampling pump to draw air through the device where the PM in the air scatters the light from a laser to assess the real-time concentration of particles smaller than 2.5 μm in $\mu\text{g}/\text{m}^3$, or PM_{2.5}. The SidePak was calibrated against a laser photometer, which had been previously calibrated and used in similar studies. In addition, the SidePak was zero-calibrated before each use by attaching a high efficiency particulate air (HEPA) filter according to the manufacturer's specifications. For each indoor venue, the first and last minute of data were removed from the statistical analysis because they are strongly influenced by outdoor and entryway air. The remaining data points were averaged to provide a mean PM_{2.5} concentration at the venue. After air monitoring, the SidePak was immediately connected to a computer, and the data were downloaded using TrakPro software, version 3.40 (TSI Inc). Observational data were entered into an Excel spreadsheet.

For the hospitality venues only, several additional variables were measured. The number of patrons and the number of burning cigarettes and waterpipes observed were recorded every 15 min during the visit. These observations were averaged over the time inside the venue to determine the average number of people on the premises and the average number of burning cigarettes and waterpipes. A sonic measure (Zircon Corporation, Campbell, CA, USA) was used to measure room dimensions, and hence the volume, of each of the hospitality venues. When using the sonic measure to calculate room dimensions was not possible, room measurements were made through visual estimation.

For estimation of occupational exposure to PM_{2.5} in the hospitality settings, an 8-h time weighted average was calculated. To derive the 8-h time weighted average from more than one sample of a shorter period, the following equation was used:

$$\frac{\{(C_1 \times T_1) + (C_2 \times T_2) \dots + (C_n \times T_n)\}}{8},$$

where C is the exposure level, T is the time for that exposure, and n is the last of the sequential sampling periods.

Statistical analysis

PM_{2.5} measurements were log₂-transformed so that their frequency distribution achieved a normal distribution. We examined the differences in means of PM_{2.5} levels in different venues by using analysis of variance (ANOVA). Dunnett's t -test was used to compare the means between venues, using the ESPRI office as the common comparison venue. Duncan's multiple range test was used to stratify venues into statistically similar groupings of PM_{2.5} levels. The contribution of cigarettes and waterpipes to each venue's mean PM_{2.5} was tested by two-way ANOVA; we also evaluated the interaction term between these two factors. Finally, quadratic terms for cigarettes and waterpipes were introduced to account for any non-linear effects. SAS version 9.3 (Statistical Analysis System, Cary, NC, USA) was used for statistical analysis.

Results

All venues

A total of 3295 measurements were analyzed in this study (Table), including 25 at Cairo International Airport, 42 in court buildings, 780 in cafes, 240 in restaurants, 449 in Ramadan tents, and 21 in a mosque, among a total of 14 categories of venues. The municipal court, with air measurements taken in the public waiting area and inside the court itself, had the highest mean level of PM_{2.5} (704.3 µg/m³), followed by the Ramadan tents (612.5 µg/m³) and cafes (478.4 µg/m³); in comparison, the smoke-free ESPRI offices and mosque had the lowest levels (72 µg/m³ and 81 µg/m³, respectively). Venues where smoking is nominally restricted but not well enforced, such as the airport, government offices, and public transport vehicles, were intermediate in the measured PM_{2.5} levels. Outdoor air measurements were relatively high (range 236–401 µg/m³), reflecting the diverse sources of particulate matter in the urban environment. The overall one-way ANOVA F -test on these log₂-transformed raw readings was highly significant ($F = 150$, $P < 0.0001$), suggesting a strong relationship between the specific type of venue and PM_{2.5} levels. Comparing venues using Dunnett's t -test showed that the mean levels of every venue, except the mosque, were significantly higher than in the control venue (ESPRI office), where a no smoking policy was strictly enforced.

Duncan's multiple range test indicated the following groupings of venues according to similarities in their PM_{2.5} levels (from highest to lowest concentrations): 1) the court

building, Ramadan tents, and cafes; 2) traffic and transportation vehicles; 3) restaurants, university buildings, governmental offices, and sidewalks; 4) airport and ambient air; 5) the rural village center; and 6) the mosque and the ESPRI office.

A two-way ANOVA model examining the impacts of cigarettes and waterpipes showed that both types of tobacco smoking contributed significantly ($F=88.58$, $P<0.0001$, and $F=12.99$, $P<0.001$, respectively) to the $PM_{2.5}$ levels in the combined group of Ramadan tents and cafes (data not shown). The quadratic term for cigarette smoking improved the fit of the model to our data, suggesting a nonlinear acceleration in $PM_{2.5}$ levels with increasing numbers of cigarettes in a venue.

Hospitality settings

$PM_{2.5}$ levels were measured in 25 hospitality settings: 15 waterpipe cafes, 5 Ramadan tents and 5 restaurants. Tobacco smoking was observed in all of them, with waterpipes predominating: the mean number of burning waterpipes was 19 in the cafes and 16 in the tents, compared to an average of 8 burning cigarettes in the cafes and 7 in the tents (data not shown). None of the restaurants had smoking patrons present during sampling. Most of the waterpipe cafes (11/15) were outdoor establishments and the remainder were indoor establishments. All tents and restaurants were enclosed indoor spaces, each with a roof and walls. No waterpipe smoking was observed in the airport, court, university, and government buildings, although cigarette smoking was observed in each of those venues. No smoking of any kind was seen in the mosque or the ESPRI office.

The average size of the sampled restaurants (128 m^3) was smaller than that of cafes and tents (235 m^3 and 2878 m^3 , respectively). The average number of patrons present during sampling in restaurants was 12 in comparison to an average of 39 in the cafes and 42 in the Ramadan tents. The mean $PM_{2.5}$ levels in open-air waterpipe cafes was $478\text{ }\mu\text{g}/\text{m}^3$ (range 100–1313) (Table). However, the average $PM_{2.5}$ level in the Ramadan tents was significantly higher, at $613\text{ }\mu\text{g}/\text{m}^3$ (range 111–1723). The 8-h time weighted average of $PM_{2.5}$ exposure level was significantly higher in Ramadan tents than in cafes ($141.6\text{ }\mu\text{g}/\text{m}^3$ vs. $56.5\text{ }\mu\text{g}/\text{m}^3$). Regarding the restaurants, the mean $PM_{2.5}$ level was $213\text{ }\mu\text{g}/\text{m}^3$ (range 105–865). The Figure shows the average levels of $PM_{2.5}$ in each of the selected venues.

Discussion

The results of the study demonstrate that venues that allowed tobacco smoking, either explicitly (cafes and Ramadan tents) or by poor enforcement of indoor smoking restrictions (courts and other government buildings), had on average much higher $PM_{2.5}$ levels than smoke-free venues (the mosque and ESPRI office) and places where no smoking was observed during the study (restaurants). Although both types of smokers were observed during the sampling sessions, waterpipe smoking predominated over cigarette smoking in the cafes and Ramadan tents. According to the indoor Air Quality Index established by the US Environmental Protection Agency (Washington, DC, USA), the indoor air quality as measured by $PM_{2.5}$ at these venues is considered very unhealthy.⁷ Our study also suggests that $PM_{2.5}$ levels were generally higher in venues in which waterpipe smoking was observed than in those in which only cigarette smoking was observed, such as in transport vehicles

and government offices, where it would not be convenient for a smoker to bring his or her own waterpipe.

The findings of this study are generally consistent with previous studies. Recent studies from the Middle East region that used comparable study designs to ours have documented similarly elevated levels of one to two orders of magnitude in venues such as waterpipe cafes compared to those where tobacco smoking was banned.^{16,19,20} In contrast, other studies have reported differences between venues that were slightly smaller than those in our study. For example, recent air monitoring in seven cities in the United States found PM_{2.5} to be 82% lower in smoke-free hospitality settings than in venues where smoking was permitted.²¹ Another study found a similar 90% decline in PM_{2.5} levels in eight hospitality venues in Delaware, USA, after smoking was prohibited there by a state law.²² One reason why our study may have observed smaller differences between smoke-free and non-smoke-free sites is the larger size of the sampled rooms and lower active smoker densities in our study, which would tend to dilute the PM_{2.5} concentration. Even in municipalities in which cigarette smoking in cafes, bars, and restaurants has been banned, regulatory loopholes have resulted in a flourishing trend of waterpipe smoking in such venues, e.g., Baltimore, MD, and New York City, NY, USA, where investigators have recently measured unacceptably high levels of PM_{2.5}, carbon monoxide (CO), and other pollutants released from waterpipes.^{23,24}

Several previous studies have assessed improvements in health associated with indoor smoking bans. For example, one study found that respiratory health improved rapidly in a sample of bartenders after a statewide smoke-free workplace law was implemented in California,¹⁰ and another study reported a 40% reduction in acute myocardial infarctions among admissions to a regional hospital during the first 6 months that a local smoke-free ordinance was in effect.²⁵ While our study did not assess health effects, it does provide a robust baseline measure of PM_{2.5} exposure levels experienced by local hospitality workers and patrons, against which future reductions in exposure can be compared when their worksites become smoke-free.

PM_{2.5} measurements have been shown to correlate well with ETS levels from cigarette smoking.²⁶ However, PM_{2.5} is only one aspect of overall air quality. Other factors such as meteorologic variables and pollutants such as nitric oxide, SO₄²⁻, ozone, nitrous oxide, and CO must also be taken into account.^{4,27} In addition, the fact that we observed elevated levels of PM_{2.5} at indoor venues where smoking is prohibited suggests that other sources, including the transport of outdoor pollution due to factory emissions and vehicle exhaust,^{28–30} may have contributed to the overall exposure burden. Biomass fuels for cooking, heating, and lighting have also been reported to result in elevated particulate levels.^{31–33}

This study is subject to several limitations. The venues selected for air measurements were a convenience sample and may not be representative of all venues in Cairo and Giza. However, these venues were selected because they offered a wide range in terms of physical size, smoking restrictions, indoor vs. outdoor settings, and waterpipe availability. In addition, ETS is not the only source of indoor PM. While PM_{2.5} monitoring is not specific for ETS, it is highly sensitive to it, as evidenced by the sharp elevation in PM_{2.5} levels upon entering venues where smoking is present. Ambient particle concentrations and traffic are

additional sources of indoor particle levels; however, PM_{2.5} levels were significantly higher in cafes and tents than in outdoor air. In contrast to the instruments available at the time of the study, current technology is capable of measuring smaller size particles, e.g., PM_{1.0} or smaller, which may better reflect the exposures originating from cigarettes and waterpipes.

Conclusions

In summary, we sought to characterize levels of PM_{2.5} in diverse indoor and outdoor venues in the Cairo metropolitan area. We took advantage of the presence of waterpipe smoking in some venues to further explore the contribution of this source of ETS to that of cigarette smoking, for which much more information is available in the literature. The results strongly suggest that waterpipe smoking can be a major contributor to both ETS and poor air quality. Ongoing tobacco control efforts in such places need to address the double burden of both types of tobacco smoking in planning for the implementation and evaluation of strategies to reduce ETS exposure.

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Figure.

PM_{2.5} levels at various sampling sites in Cairo, Egypt, 2005–2006. ESPRI = Egyptian Smoking Prevention Research Initiative; PM_{2.5} = particulate matter <2.5 µm in diameter.

Table

PM_{2.5} levels (in $\mu\text{g}/\text{m}^3$) in the sampled venues in Cairo and Giza, Egypt

Venue	Air samples <i>n</i>	Mean $\pm$ SD	Median [IQR]	Maximum	Minimum
Hospitality settings					
Restaurants (<i>n</i> = 5)	240	297.9 $\pm$ 183.9	231 [216]	865	105
Cafes (<i>n</i> = 15)	780	478.4 $\pm$ 225.2	444 [292]	1313	100
Ramadan tents (<i>n</i> = 5)	449	612.6 $\pm$ 385.7	590 [531]	1723	111
Public venues					
Airport (<i>n</i> = 1)	25	171.5 $\pm$ 41.1	178 [35]	240	80
University buildings (<i>n</i> = 1)	16	223.0 $\pm$ 13.4	219 [28]	244	207
Courts (<i>n</i> = 2)	42	704.3 $\pm$ 316.6	743 [488]	1297	80
Transport vehicles (<i>n</i> = 8)	200	346.4 $\pm$ 217.0	320 [149]	1330	72
Government offices (<i>n</i> = 3)	112	321.4 $\pm$ 345.8	204 [109]	1176	76
Open air venues					
Ambient air (<i>n</i> = 22)	485	236.8 $\pm$ 134.4	209 [222]	730	47
Village center (<i>n</i> = 1)	93	102.5 $\pm$ 25.0	96 [27]	236	68
Sidewalks (<i>n</i> = 3)	92	253.2 $\pm$ 144.1	240 [145]	1003	74
Crosswalks (<i>n</i> = 28)	631	401.3 $\pm$ 260.0	366 [367]	1399	41
Smoking-restricted venues					
Mosque (<i>n</i> = 1)	21	81.1 $\pm$ 7.2	80 [9]	96	72
ESPRI office (<i>n</i> = 1)	109	72.1 $\pm$ 9.8	70 [13]	106	55

PM_{2.5} = particulate matter <2.5 μm in diameter; SD = standard deviation; IQR = interquartile range; ESPRI = Egyptian Smoking Prevention Research Initiative.