Original Article

Global Air Monitoring Study: A Multi-country Comparison of Levels of Indoor Air Pollution in Different Workplaces†

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Abstract

Introduction: A local study completed in Singapore, which was part of an international multi-country study that aims to develop a global assessment of exposure to second-hand smoke in indoor workplaces, gathered data regarding the indoor air quality of public areas. It was hypothesised that air would be less polluted in non-smoking venues compared to places where smoking occurred. Materials and Methods: A TSI SidePak AM510 Personal Aerosol Monitor was used to sample and record the levels of respirable suspended particles (RSP) in the air. A broad range of venues were sampled in Singapore. The primary goal of data analysis was to assess the difference in the average levels of RSP in smoke-free and non smoke-free venues. Data was assessed at 3 levels: (a) the mean RSP across all venues sampled compared with the mean levels of smoke-free and non smoke-free venues, (b) levels in venues where smoking occurred compared with similar venues in Ireland, and (c) comparison between smoke-free and non smoke-free areas according to the type of venue. Statistical significance was assessed using the Mann-Whitney U-test. Results: The level of indoor air pollution was 96% lower in smoke-free venues compared to non smoke-free venues. Averaged across each type of venue, the lowest levels of indoor air pollution were found in restaurants (17 µg/m^3) and the highest in bars (622 µg/m^3); both well above the US EPA Air Quality Index hazardous level of ≥251 ug/m^3. Conclusions: This study demonstrates that workers and patrons are exposed to harmful levels of a known carcinogen and toxin. Policies that prohibit smoking in public areas dramatically reduce exposure and improve worker and patron health.

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Key words: Hospitality, $PM_{2.5}$, Second-hand smoke, Smoke-free

Introduction

Second-hand smoke is a mixture of the smoke given off by the burning end of a cigarette, pipe or cigar, and the smoke exhaled from the lungs of smokers. There are more than 4,000[1-3] chemicals in second-hand smoke including 69[1-3] carcinogens as well as other chemicals that are irritants, toxicants and mutagens.[4] In 1986, a report of the United States (US) Surgeon General concluded that second-hand smoke is a cause of disease in healthy non-smokers.[5] Subsequent studies from the US Environmental Protection Agency,[6,7] the US National Toxicology Programme[8] and the International Agency for Research on Cancer[9] have classified second-hand smoke as a known human carcinogen.

Ireland became the first nation to implement smoke-free worksite regulations that included bars and restaurants in March 2004. Norway implemented its policy in June 2004. New Zealand, Sweden, Scotland, the United Kingdom and Uraguay have also passed similar regulations, to name a few. Through state or provincial regulations, large parts of Australia, Canada and the US have strong clean indoor air regulations. While this is very encouraging, smoking in indoor public places is still the norm in the vast majority of nations worldwide. On July 6 2007, 146 countries met at a World Health Organization (WHO) Framework Convention on Tobacco Control (FCTC)[10,11] to draw up international protocols against cigarette smuggling as well as to agree on

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† This report is part of a global study with data collected in Singapore, Australia, Belgium, Brazil, Canada, China, Cyprus, Egypt, France, Germany, Greece, India, Ireland, Israel, Italy, Japan, Laos, Malaysia, New Zealand, Pakistan, Poland, Portugal, Romania, Russia, Singapore, South Korea, Spain, Switzerland, Syria, Thailand, United Kingdom, United States, Uruguay, Venezuela and Vietnam.

strict definitions of what it means to have a smoke-free bar or office. These guidelines include the statement that "there is no safe level of exposure to tobacco smoke", and specifications that half-measures such as designated smoking areas, air filtration or ventilation do not work.

The goal of this study is to provide the latest scientific equipment and methods to practitioners around the world in at least 20 different countries and develop a global scorecard of second-hand smoke exposure. In each country, efforts were made to test air quality in each of the following: restaurants, bars, transportation centres (airports, train stations), hotels, shopping malls, offices and other outdoor ambient air venues. It was hypothesised that indoor air would be less polluted in venues where smoking is prohibited or does not occur, as compared to places where smoking is present (Fig. 1).

Current Status of Smoke-free Legislation in Singapore

For Singapore, legislations against smoking have come a long way since their introduction in the early 1970s. From 1986 to 2001, the National Smoking Control Programme (NSCP) and the Committee on Smoking Control (CSC) managed the anti-smoking control measures. In 2001, the Health Promotion Board was formed to manage and promote health programmes, including smoking control and education.[12] The year 2004 saw the unprecedented development of a pub heeding the National Cancer Centre's call to become smoke-free. In the subsequent year, the National Environment Agency announced plans to implement more widespread smoking bans. This ban was first put into effect in October 2005 at public swimming complexes, open-air stadiums, community clubs, toilets, bus stands, shelters and bus interchanges. It was further extended to public eating places in October 2006, and with effect from July 2007, pubs, clubs and karaoke lounges have gone smoke-free as well.

These encouraging developments have, and will, continue to contribute much towards ensuring a healthier nation. Scientific proof needs to be translated into action before it can have the desired effects, and this is an area in which government bodies have an indispensable role to play.

In conjunction, the National Cancer Centre has participated in the joint global air monitoring study. This study was done in partnership with the International Agency for Research on Cancer to determine the quality of air in indoor environments where smoking is permitted.

Materials and Methods

The data presented here from Singapore is part of a larger study, which included over 20 different countries. Air quality was tested in each of the following: restaurants, bars, transportation areas, including airports and train stations, and other types of venues, such as hotels, shopping malls, offices and outdoor ambient air venues.

A TSI SidePak AM510 Personal Aerosol Monitor (TSI Inc., St. Paul, Minnesota, USA) was used to sample and record the levels of respirable suspended particles (RSP) in the air (Fig. 2). The SidePak uses a built-in sampling pump to draw air through the device. Particulate matter in the air scatters the light from a laser to assess the real-time concentration of particles less than 2.5 μm in micrograms per cubic metre, or $PM_{2.5}$. $PM_{2.5}$ is the concentration of particulate matter in the air smaller than 2.5 microns in diameter, which are easily inhaled deep into the lungs. Particles of this size are released in significant amounts from burning cigarettes. Hence, the $PM_{2.5}$ may be used as a strong indicator of exposure to carcinogenic second-hand smoke (SHS). Long-term annual exposures are linked to an approximate 4% increased risk of death from all natural causes, a 6% increased risk of death from cardiopulmonary disease, and an 8% increased risk of death from lung cancer for each 10 mcg/m^3 increase in long-term average $PM_{2.5}$ concentrations.[13,14] Short-term exposures (≤24 hours) are known to exacerbate underlying conditions. For example, exposure to a raised $PM_{2.5}$ was associated with a 4.5% increased risk of unstable angina and myocardial infarction, especially in individuals with existing coronary artery disease in a case-crossover study by Pope CA et al.[14]

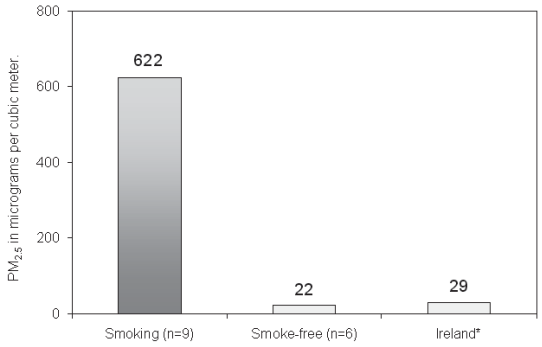
The SidePak was calibrated against a standardised light scattering instrument, which had been previously calibrated and used in other similar studies. In addition, the SidePak was zero-calibrated prior to each use by attaching a HEPA filter according to the manufacturer's specifications.

While second-hand smoke is not the only source of indoor particulate matter, $PM_{2.5}$ monitoring is highly sensitive to it. Ambient particle concentrations and cooking are additional sources of indoor particle levels, but smoking is by far the largest contributor to indoor air pollution.[15] Furthermore, there is a direct link between the level of RSP and polycyclic aromatic hydrocarbons (PAH), which are known carcinogens in cigarette smoke, with RSP levels being approximately 3 orders of magnitude greater than PAH's.[7]

The equipment was set to a one-minute log interval, which calculates the average of the preceding 60 one-second measurements. Sampling was discreet in order not to disturb the occupants' normal behaviour. The monitor was generally located in a central location on a table or bar and not on the floor so the air being sampled was within the occupants' normal breathing zone. For each venue, the first and last minute of logged data were removed as they included measurements of outdoors and entryway air. The remaining data points were averaged to obtain the mean $PM_{2.5}$ concentration within the venue. Sampling was

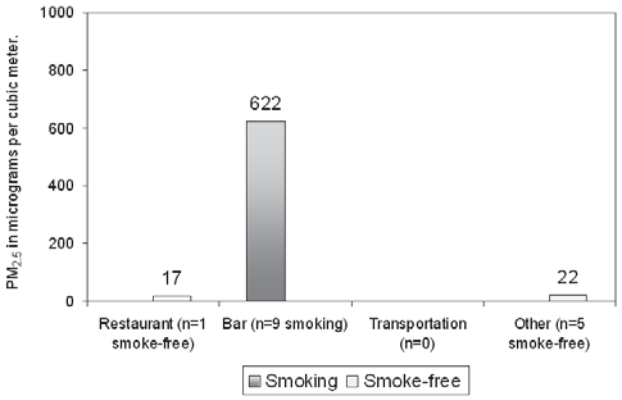
Fig. 1. The participating countries in the Global Air Monitoring Study.

Fig. 2. TSI SidePak AM510 Personal Aerosol Monitor.



*Average PM2.5 level in Ireland following a comprehensive smoking ban.
Note: The difference between smoking and smoke-free venues is statistically significant, p<0.001 from a Mann-Whitney U-test.

Fig. 3. Average fine particle air pollution.



Note: The difference between smoking and smoke-free venues is statistically significant, p<0.001 from a Mann-Whitney U-test.
"Other" types of venues include a hotel lobby, food mall, and a hospital.

Fig. 4. Average fine particle air pollution by type of venue.

Air Quality	Air Quality Index	$PM_{2.5}$ (μg/m³)	Health Advisory
Good	0-50	≤15	None.
Moderate	51-100	16-40	Unusually sensitive people should consider reducing prolonged or heavy exertion.
Unhealthy for Sensitive Groups	101-150	41-65	People with heart or lung disease, older adults, and children should reduce prolonged or heavy exertion.
Unhealthy	151-200	66-150	People with heart or lung disease, older adults, and children should avoid prolonged or heavy exertion. Everyone else should reduce prolonged or heavy exertion.
Very Unhealthy (Alert)	201-300	151-250	People with heart or lung disease, older adults, and children should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.
Hazardous	≥301	≥251	

Fig. 5. US EPA Air Quality Index.

performed by associates in Singapore, and the data was analysed by the Roswell Park Cancer Institute staff.

Sampling of Venues

Fifteen venues were sampled in Singapore. The venues were selected to obtain a broad range of size, location and type of venue. Venues included bars, restaurants and a hospital. Table 1 presents some general descriptive information on the size and occupancy of each venue.

Statistical Analyses

The primary goal was to assess the difference in the average levels of RSP in places that were smoke-free (no smoking observed during sampling) and places that were not (smoking was observed during sampling). Within each country, the mean RSP is reported across all of the venues sampled and these are then compared with the mean levels of all venues in the entire sample that were "smoke-free" and those that were not. Additionally, levels in venues where smoking occurred were compared with levels in venues in Ireland where there is a comprehensive smoking policy. The data from Ireland come from another study and are included as a reference group for the data in this study.[16] Finally, the comparison between smoking and smoke-free venues is replicated for each type of venue. Statistical significance is assessed using the Mann-Whitney U-test.

Results

Table 1 presents detailed information about each venue sampled. Levels of indoor air pollution ranged from 11 to 1605 μg/m³.

Six of the venues sampled were smoke-free (no smoking

Table 1. Average $PM_{2.5}$ Level in Each Venue

Venue #	Type	Volume (m^3)	People (mean)	Cigarettes (mean)	Smoker Density*	Mean $PM_{2.5}$ (ug/m^3)
1	Bar	720	20	5.0	0.69	88
2	Bar	600	14	6.0	1.00	672
3	Bar	263	25	12.0	4.57	226
4	Bar	298	32	11.0	3.70	820
5	Bar	400	24	10.0	2.50	254
6	Bar	400	23	10.0	2.50	1605
7	Bar	184	32	9.0	4.90	813
8	Bar	280	23	7.0	2.50	274
9	Bar	800	36	16.0	2.00	850
10	Other	6750	20	0.0	0.00	18
11	Other	25,000	100	0.0	0.00	39
12	Other	12,500	73	0.0	0.00	19
13	Outside				27	
14	Restaurant	1000	30	0.0	0.00	17
15	Other	1200	43	0.0	0.00	11
Total		**3600**	**35**	**6.1**	**1.74**	**382**

* Average number of burning cigarettes per 100 m^3

was observed), and the average level of $PM_{2.5}$ in these venues was 22 $\mu g/m^3$. Smoking was observed in 9 of the venues sampled, and the average level of $PM_{2.5}$ in these venues was 622 $\mu g/m^3$. The level of indoor air pollution was 96% lower in venues that were smoke-free compared to venues where smoking was observed, and this difference was statistically significant (P <0.001) as determined by the Mann-Whitney U-test (Fig. 3).

Averaged across each type of venue, the lowest levels of indoor air pollution were found in restaurants (17 $\mu g/m^3$) and the highest levels were found in bars (622 $\mu g/m^3$) (Fig. 4).

Discussion

In the US, the EPA cited over 80 epidemiologic studies in creating a particulate air pollution standard in 1997.[17] In order to protect public health, the EPA has set limits of 15 $\mu g/m^3$[4,5] as the average annual level of $PM_{2.5}$ exposure. Based on the latest scientific evidence, EPA staff currently propose even lower $PM_{2.5}$ standards to adequately protect public health,[18] making the current high $PM_{2.5}$ exposures of people in smoking environments even more alarming.

Previous studies have evaluated air quality by measuring the change in levels of RSP between smoke-free venues and those that permit smoking. Ott et al[19] did a study of a single tavern in California and showed an 82% average decrease in RSP levels after smoking was prohibited by a city ordinance. Repace[20] studied 8 hospitality venues in Delaware before and after a statewide prohibition of smoking in these types of venues and found that about 90% of the fine particle pollution could be attributed to tobacco smoke. Similarly, in a study of 22 hospitality venues in Western New York, Travers et al[21] found a 90% reduction in RSP levels in bars and restaurants, and 84% reduction in large recreation venues such as bingo halls and bowling alleys, and even a 58% reduction in locations where only SHS from an adjacent room was observed at baseline. A cross-sectional study of 53 hospitality venues in 7 major cities across the US showed 82% less indoor air pollution in the locations subject to smoke-free air laws, even though compliance with the laws was less than 100%.[22] The US EPA Air Quality Index (Fig. 5) gives a guideline to assessing the severity of air pollution according to the level of $PM_{2.5}$ (mg/m^3) in the air.

Other studies have directly assessed the role SHS exposure has on human health. One study found that respiratory health improved rapidly in a sample of bartenders after a state smoke-free workplace law was implemented in California,[23] and another study reported a 40% reduction in acute myocardial infarctions in patients admitted to a regional hospital during the 6 months that a local smoke-free ordinance was in effect.[24] Farrelly et al[25] also showed a significant decrease in both salivary cotinine concentrations and sensory symptoms in hospitality workers after New York State's smoke-free law prohibited smoking in their worksites.

Conclusions

Hospitality venues that allow indoor air smoking in Singapore are significantly more polluted than both indoor smoke-free sites and outdoor air in Singapore. This study demonstrates that workers and patrons in such venues are exposed to harmful levels of a known carcinogen and toxin, with the average level of $PM_{2.5}$ (622 $\mu g/m^3$) being well above the hazardous level (≥251 $\mu g/m^3$) of the US EPA Air Quality Index. Policies that prohibit smoking in public worksites dramatically reduce second-hand smoke exposure and improve worker and patron health.

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