Occupational Exposure to Polycyclic Aromatic Hydrocarbons: A Cross-Sectional Study in Bars and Restaurants in Santiago, Chile

Claudio Muñoz, PhD,[1,2] Andrea Droppelmann, BSBC,[3] Marcia Erazo, PhD,[4] Paulina Aceituno, MPH,[4] Cecilia Orellana, MPH,[4] Javiera Parro, MPH,[4] Sthepanie Mesias, MPH,[4] Nella Marchetti, BChE,[4] Ana Navas-Acien, PhD,[5] and Verónica Iglesias, PhD[4]*

Objective *To evaluate indoor polycyclic aromatic hydrocarbon (PAH) concentrations in bars and restaurants and identify the main determinants of airborne PAH concentrations.*
Methods *This study included 57 bars/restaurants in Santiago, Chile. PAH concentrations (ng/m^3) were measured using photoelectric aerosol sensor equipment (PAS 2000CE model). Nicotine concentrations (µg/m^3) were measured using active sampling pumps followed by gas-chromatography. Linear regression models were used to identify determinants of PAH concentrations.*
Results *PAH concentrations were higher in venues that allowed smoking compared to smoke-free venues. After adjusting, the air PAH concentrations were 1.40 (0.64–3.10) and 3.34 (1.43–7.83) ng/m^3 higher for tertiles 2 and 3 of air nicotine compared to the lowest tertile.*
Conclusions *In hospitality venues where smoking is allowed, secondhand smoke exposure is a major source of PAHs in the environment. This research further supports the importance of implementing complete smoking bans to protect service industry workers from PAH exposure.* Am. J. Ind. Med. 59:887–896, 2016. © 2016 Wiley Periodicals, Inc.

KEY WORDS: polycyclic aromatic hydrocarbons; environmental tobacco smoke; nicotine; workplace; occupational health

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are the product of incomplete combustion of natural and man-made organic materials and have been identified as environmental and occupational public health risks [Lewtas, 2007]. Experimental research has demonstrated a link between PAHs and lung cancer [National Research Council, 1986; Glantz and Parmley, 1991]. In humans, epidemiologic research has shown that PAHs are associated with increased risk of cancer as well as respiratory and cardiovascular disease [Harrison and Johnston, 1985; National Institute for Occupational Safety and Health, 1991; ATSDR, 1995; EPA, 1992; WHO, 2004; Surgeon General's Report, 2006; Vardoulakis et al., 2008]. Fossil fuels, candles, wood, and tobacco are well known sources of PAH exposure. In outdoor spaces, PAHs from industrial emissions and motor vehicles contributes to urban air pollution [Lewtas, 2007]. In indoor spaces, secondhand tobacco smoke (SHS) is a direct although non-specific source of PAHs and poses a potential health hazard to service industry workers, who are exposed to high levels of SHS [Denissenko et al., 1996].

[1]Doctorate Program in Public Health, Faculty of Medicine, School of Public Health, University of Chile, Santiago, Chile
[2]Department of Public Health, Faculty of Medicine, University of La Frontera, Temuco, Chile
[3]Occupational Health Laboratory, Institute of Public Health of Chile, Santiago, Chile
[4]Faculty of Medicine, School of Public Health, University of Chile, Santiago, Chile
[5]Bloomberg School of Public Health, Johns Hopkins University, Baltimore, Maryland
*Correspondence to: Verónica Iglesias Alamos, Faculty of Medicine, Department of Epidemiology, School of Public Health, University of Chile, Independencia 939, Independencia, Santiago, Chile. E-mail: viglesia@med.uchile.cl

Accepted 10 May 2016
DOI 10.1002/ajim.22616. Published online 27 June 2016 in Wiley Online Library (wileyonlinelibrary.com).

While active smoking is well-recognized as source of PAH exposure, relatively few studies, however, have evaluated the role of SHS as a source of PAHs. Few studies, moreover, have measured PAHs concentrations in restaurants and bars. Documenting PAH exposure levels in hospitality venues and identifying the main sources is important to provide reference information regarding PAH exposure and to identify effective strategies to reduce workers' exposure to PAHs in hospitality venues. In addition, research is needed to evaluate additional relevant sources of PAHs in hospitality venues, and the relative contribution of SHS exposure compared to other sources.

Chile has the highest smoking prevalence in Latin America. According to a report of the Pan American Health Organization, the standardized prevalence of tobacco consumption in adult population in 2011 was 41% in Chile, 25% in Uruguay, 17% in Brazil, and 7% in Barbados [PAHO, 2013]. Among adolescents (13–15 years) the prevalence of tobacco consumption varied from 35.1% in Chile to 2.8% in Canada. Chile ratified the World Health Organization's Framework Convention on Tobacco Control in 2005 [WHO, 2003]. In 2010, at the date of this research, the smoking legislation enacted allowed smoking inside hospitality venues [MINSAL, 1995], resulting in excessive exposure to SHS among bar and restaurant employees [Aceituno et al., 2010; Erazo et al., 2010]. The goal of this study was to evaluate indoor PAH concentrations in a sample of bars and restaurants in Santiago, Chile, and to identify the main determinants of exposure to PAHs, including SHS measured using air nicotine concentrations, among hospitality employees.

METHODS

Design and Study Population

This project is part of a cross-sectional exposure assessment study conducted in bars and restaurants in Santiago, Chile, between September 2010 and January 2011. The study was designed to evaluate SHS exposure in hospitality venues following the enactment of an incomplete smoking ban legislation in 2007. Because the study included assessment of SHS exposure in workers in addition to venues, the criteria for venue eligibility was to be a bar-pub (establishment in which customers consume small dishes, appetizers, some food such as tapas, snacks, among others) or restaurant (establishment in which customers consume food a la carte or menu) and had at least three non-smoking workers. We estimated that we would need to recruit 66 venues to reach our goal of 200 workers. One of the aims of the framework study was to determine the prevalence of respiratory symptoms measured as a percentage of affected workers. The sample size estimate was made considering the following parameters: confidence level of 95%, a sampling error of 3.3% and a maximum variance of 0.25. The estimated sample size was 200 employees, this size obtained by designing the survey would allow assess statistical hypothesis considering an alpha level of 0.05, power of 80%, two categories and an effect size of 0.40. In a preview study conducted in Santiago, it was reported that the median of non-smoking workers by local was 3 [Aceituno et al., 2010]. According to that information and the sample size required, we estimated that we needed to select 66 establishments to recruit the estimated number of participants. Initially we considered an oversampling of 20% extra venues (n = 14). To identify potential participating venues a sampling frame of establishments was constructed by the research team. The National Institute of Statistics provided us the number of hospitality venues by municipality in the city of Santiago. We choose the five municipalities with the greatest concentration of hospitality venues (n = 4168). Members of the research team walked the streets and visited 690 venues. All venues visited were close to each other in each of the five municipalities. In each venue the manager or person in charge were asked about the name of the establishment, address, name, and phone number of contact person, type of establishment (bar-pub/restaurant/other), smoking status of the venue (smoking allowed in all areas/mixed policy (smoking and non-smoking areas)/non-smoking in all areas) and number of non-smoking employees. A total of 207 establishments meeting the eligibility criteria, 108 were selected and their owners/managers were contacted in person to explain the study objectives. A total of 63 (58%) agreed to participate and signed an informed consent. Those who did not agree indicated a lack of time or lack of interest in the study. Four venues were not evaluated due to time scheduling restrictions. The number of establishments assessed in the main study was 59.

In the present study we included only 57 establishments. In two venues we were unable to measure PAH concentrations because the battery did not worked. By smoking status of the venue, 24 allowed smoking in all areas, 23 had mixed areas, and 10 were non-smoking venues. The research protocol and informed consent were approved by the Ethics Committee for Human Subjects Research of the Faculty of Medicine, University of Chile.

Polycyclic Aromatic Hydrocarbon Concentrations

The primary outcome variable was indoor air PAH concentrations, which was measured using an aerosol photoelectric sensor (PAS 2000 CE model, EcoChem Analytics) [Evans et al., 2010]. This monitor measures just particle-bound PAHs on ultrafine particulate matter, which may under estimate the potential exposure to total PAHs (including gas phase PAHs). All measurements were conducted using a procedure manual and trained personnel. The device recorded PAH concentrations each minute, in nanogram/cubic meter (ng/m^3), making a direct reading of the components, ranging between 0 to 4,000 ng/m^3. The device has a sensivity of 10 ng/m^3 and has been used in previous studies [Marr et al., 2004]. The device was placed at 1-m height on a table located in a central indoor area of the venue when the facilities were open to the public. In establishments with mixed smoking policy (smoking and non-smoking areas), measurements were taken in the smoking area as the employees have to spend time in both areas. Measurements were performed for 30 min during a time of high occupancy (13–15 PM or 19–24 PM). Outdoor PAH concentrations were also measured outside the venue for 30 min, with the goal of controlling for environmental PAH concentrations that may drift into the facility. This measurement was performed immediately after the indoor monitoring.

The sensitivity of PAH measurements to SHS were evaluated during a pilot study. The study consisted of an experiment in which smoking volunteers smoked 1, 3, 4, or 10 cigarettes over a period of 60 min in a room. Nicotine, PAHs, and particulate matter of less than 2.5 μm aerodynamic diameter [$PM_{2.5}$] were measured at the same time. A laser photometer $PM_{2.5}$ (Dustrak, TSI) was used for $PM_{2.5}$ measurements. The objective was to evaluate the correlation between the number of cigarettes and concentration of environmental pollutants using our study instruments. The correlation was very strong and significant for the number of cigarettes with air PAHs concentrations (Spearman = 0.84, P-value <0.001); $PM_{2.5}$ concentrations (Spearman = 0.91, P-value <0.001) and air nicotine concentrations (Spearman = 0.99, P-value <0.001). The correlation between air nicotine and air PAH concentrations during the experiments was 0.74 (P-value <0.001).

Other Measurements

We evaluated SHS exposure by measuring indoor air nicotine concentrations, a specific marker of SHS, using active pumps (model SKC222-44XR, USA). The equipment was installed at 1-m height in a central area in smoking and non-smoking venues. In mixed venues, we placed two separate (but simultaneous) pumps, one in the smoking section and another one in the non-smoking section. The nicotine measurements in the smoking sections were made at the same location as the PAH measurements. Air nicotine concentrations were measured for 60 min and coinciding in part with the PAH measurements. The pumps were calibrated daily using a digital calibrator (SKC Ultraflow, USA). The samples were collected using a 37 mm filter treated with bisulfate, at a flow of 1,500 ml/min. To determine the nicotine mass in the filters, gas chromatography was performed at the Occupational Health Laboratory of the Public Health Institute of Chile. The nicotine detection limit was 0.8 μg/ml, a value equivalent to 2.2 $\mu g/m^3$ consider a 60-min sample at a flow of 1,500 ml/min. A total of 21 samples (36.8%) had nicotine concentrations below the detection limit, five in venues that allowed smoking everywhere (20.8%), eight in mixed venues (34.8%), and eight in non-smoking venues (80.0%). Samples below the detection limit were assigned a value equivalent to half the detection limit (1.1 $\mu g/m^3$).

Structured, interview-based questionnaires were completed by the venue owners to gather data on other variables that can contribute to PAH concentrations: type of venue (bar/restaurant); smoking status of the venue (smoking allowed/mixed policy/comprehensive non-smoking policy); use of ventilation systems (yes/no): if yes, presence of air conditioning (yes/no), active air extraction in the point where contaminants are generated (in our study in the customer area as we did not assessed the kitchens) to capture them and send them outside through connecting ducts (yes/no) and/or fan (yes/no); estimated number of customers per day; estimated surface area of establishment ($<100\,m^2$, $>100\,m^2$, unknown); estimated percentage of customers who smoked; isolation of the food preparation area from the customer area (completely/partially/no isolation), type of food sold in the establishment (full menu/small plates or no sale of food), type of stove (gas or no stove). Additional information noted through observations was collected at the same time that PAH concentrations were measured, including characteristics of the establishment ventilation system, number of customers, number of smokers, and other sources of combustion as candles or incense, heating systems and local traffic flow. This last variable refers to type of street where the venue is located since the combustion of diesel is an additional source of PAHs. Streets with more than two tracks where buses and cars circulate where considered high traffic. Streets with one or two tracks but only with cars running were considered medium traffic. If the venue is located on a road with little traffic or away from a street, we considered it to have low traffic.

Statistical Analyses

The data were entered into a database using the EpiData program, with double data entry to minimize error. Stata 12.0 (Stata Corporation, Texas, TX) was used for all statistical analyses. An exploratory analysis was performed to examine the distribution of continuous variables. Because PAHs and nicotine concentration were right skewed (non-normally distributed using the Shapiro–Wilk test), the data were logarithmically transformed to improve normality. Descriptive statistics (frequency, median, percentile 25-percentile 75 (P_{25}–P_{75})) were used to summarize the main variables. Median air PAHs and nicotine concentrations were determined for the categories of each variable, and differences between categories were tested using the Mann–Whitney test or Kruskal–Wallis test when there were two or three categories, respectively. The bivariate associations between continuous variables were explored using Spearman correlation test. We used linear regression models on log-transformed PAH concentrations to compute the crude and multivariable adjusted ratio of the geometric mean of PAH concentrations and its 95% confidence interval comparing air nicotine tertiles 2 and 3 to the lowest tertile. The geometric mean ratio was obtained by exponentiating the beta coefficient of the model. In addition to tertiles, we also modeled air nicotine as natural log. Multivariable models were adjusted for outdoor PAH concentrations (tertiles), vehicular traffic in the closest street (low/medium/high), use of candles (yes/no) and venue surface area ($<100\,m^2$, $>100\,m^2$, unknown). We conducted analyses overall, and stratified by smoking policy status of the venue. We also conducted an analysis of the association between air nicotine and air PAHs in venues without using candles.

RESULTS

Establishment Characteristics

Among the 57 establishments, 36.8% were pubs/bars and 63.2% were restaurants (Table I). Smoking establishments represented 42.1%, establishments with mixed smoking policy 40.4%, and non-smoking establishments 17.5%. Most venues (57.9%) were larger than $100\,m^2$. The legal occupancy was over 100 people in 50.0%. Nearly all venues (96.5%) used a gas stove to prepare food. The other two venues (bars) have no kitchen. In 55.4% establishments, the owners estimated that the percentage of customers who smoked exceeded 50%. The establishments located in high vehicle traffic zones represented 43.9% of the total.

The predominant ventilation system was the fan (52.4%), followed by active extraction and/or air conditioning (31.0%). The use of windows was also a ventilation method (33.3%), along with doors open to the outside (70.2%). In smoking establishments, 91.7% kept the doors open and 45.8% kept the windows open. Mixed establishments also used doors and windows as ventilation methods (43.5% and 30.4%, respectively). A 17.5% (n = 11) use candles or incense, seven of them were bars and four were restaurants.

Air PAH Concentrations

Median (P_{25}–P_{75}) indoor air PAH concentrations was 113.0 (51.0–280.5) ng/m^3, markedly greater than outdoor PAH concentrations 71.0 (41.0–142.0) ng/m^3 (Table II). Median PAH concentrations were four times higher in venues with air nicotine concentrations in tertile 3 compared to tertile 1 (280.5 vs. 64.0 ng/m^3). Smoking venues had two times higher PAH concentrations (152.0 ng/m^3) than mixed venues (83.5 ng/m^3), and six times higher than non-smoking venues (24.5 ng/m^3). Indoor air PAH concentrations also varied significantly ($P < 0.01$) by type of establishment and square meters of the surface (Table II).

In terms of ventilation, establishments using at least one ventilation system during the measurement period had significantly higher environmental PAH concentrations than those that did not report use of any system ($P < 0.001$). The pub/bar with ventilation was the type of establishment with higher median PAH concentration (242 ng/m^3) compared with pub/bur without ventilation (88.5 ng/m^3) or restaurant with (73.8 ng/m^3) or without ventilation (85.5 ng/m^3). The median PAH concentrations inside establishments using a fan was 240.5 ng/m^3, higher than for establishments using air conditioning (94.5 ng/m^3) and active air extraction (146.0 ng/m^3).

Regarding the preparation of food, no venues used grilling or wood stove as potential sources of PAHs and the median PAH concentrations in establishments with gas stove (most of them restaurants) was 113 ng/m^3 and in establishments with no stove (two bars) was 319.5 ng/m^3. When the food preparation area was completely isolated from the customer area (n = 36), the median PAH concentrations was 94 ng/m^3, when it was partially isolated (n = 18) the median PAH concentration was 188.5 ng/m^3 and when it was not isolated (n = 2) the median PAH concentration was 134.5 ng/m^3.

We found that 11 establishments used candles (n = 10) or incense (n = 1) during the measurement period. In these establishments, median environmental PAH concentration was 667.0 ng/m^3 (P_{25}–P_{75} 101.0–1978.5). The median PAH concentration in bars with use of candles and incense (n = 7) was 258.0 (P_{25}–P_{75}, 101.0–2445) ng/m^3 while in bars without used of candles or incense (n = 14) the median PAH concentration was 150 (P_{25}–P_{75}, 88.5–423.0) ng/m^3. The median PAH concentration in restaurants with use of candles and incense (n = 4) was 1168 ng/m^3 (P_{25}–P_{75}, 364.0–1823.8) while in restaurants without use of candles or incense (n = 32) the median PAH concentration was 72.5 (P_{25}–P_{75}, 26.0–150.0) ng/m^3. According to smoking status of the establishment, smoking allowed venues that use candles or incense (n = 6) had a median PAH concentration of 190 ng/m^3 (P_{25}–P_{75}, 101.0–1413.5) and the median PAH concentration in smoking allowed venue without use of candles or incense (n = 18) was 152 (P_{25}–P_{75}, 90.0–423.0) ng/m^3, while in mixed establishments with use of candles or incense (n = 4) the median PAH concentration was 1168 ng/m^3 (P_{25}–P_{75}, 359.0–2057.0) and without use of candles or incense was 81.0 ng/m^3 (P_{25}–P_{75}, 31.5–149). We had just one non-smoking establishment with use of candles or incense, with a PAH concentration of 1978.5 ng/m^3. In non-smoking establishment without use of candles or incense (n = 9), the median PAH concentration was 21.0 (P_{25}–P_{75}, 19.0–30.0) ng/m^3.

TABLE I. Characteristics of the Establishments According to Smoking Status, Santiago, Chile, 2010–2011

	Total (n = 57)	Smoking (n = 24)	Mixed (n = 23)	Non-smoking (n = 10)
Type of establishment, %				
Pub–Bar	36.8	70.8	17.4	0.0
Restaurant	63.2	29.2	82.6	100
Surface area of establishment (m^2), %				
Less than 100	33.3	50.0	26.1	10.0
Greater than 100	57.9	29.2	73.9	90.0
Unknown	8.7	20.8		
Maximum capacity, median (P_{25}–P_{75})	106.0 (67.5–155.0)	80.0 (53.5–100)	135.0 (100–200)	130.0 (70.0–200.0)
Number of workers, median (P_{25}–P_{75})	12.0 (7.0–20.0)	9.0 (5.5–12.0)	16 (11.0–23.0)	18.5 (9.0–43.0)
Ventilation system, %				
Yes	73.7	62.5	78.3	90.0
Air conditioning, %	31.0	26.7	27.8	44.4
Active air extraction, %	31.0	20.0	33.3	44.4
Fan, %	52.4	66.7	38.9	55.6
Doors open to the outside, %	70.2	91.7	43.5	80.0
Windows open to the outside, %	33.3	45.8	30.4	10.0
Local traffic, %				
High	43.9	54.2	43.5	20.0
Medium	49.1	45.8	47.8	60.0
Low	7.0	0.0	8.7	20.0
Type of food sold in the establishment				
Full menu	68.4	50.0	82.6	80.0
Small plates or no sale of food	31.6	50.0	17.4	20.0
Food preparation area isolated				
Yes, completely	64.3	56.5	82.6	40.0
Yes, partially	32.1	43.5	17.4	40.0
No	3.6	0.0	0	20.0
Type of stove, %				
Gas	96.5	91.7	100.0	100.0
Heating system, %				
No	96.5	100.0	95.7	90.0
Candles or incense, %				
Yes	17.5	20.8	17.4	10.0

Air Nicotine Concentrations

Nicotine concentration varied significantly by smoking status of the establishment ($P < 0.01$), with a median of 3.72 μg/m^3 (P_{25}–P_{75} 1.26–7.20) in smoking establishments, 2.43 μg/m^3 (P_{25}–P_{75} 1.10–7.66) in the smoking section of mixed establishments, and 1.10 μg/m^3 (P_{25}–P_{75} 1.10–3.80) in the non-smoking section of mixed establishments. In non-smoking establishments, 80% of the filters had nicotine levels below the detection threshold. Pubs and bars also had markedly higher air nicotine concentrations compared to restaurants (median 3.83 vs. 1.31 μg/m^3, $P < 0.001$) (Table II). Air nicotine concentrations varied significantly ($P < 0.001$) by venue surface area, with greater concentrations in establishments larger than 100 m^2.

Relationship Between Air PAH and Nicotine Concentrations

Air PAH concentrations were correlated with air nicotine concentrations in smoking venues (Spearman = 0.67; $P < 0.001$) and in the smoking section of mixed venues (Spearman = 0.45; $P = 0.03$) (Fig. 1). In establishments where smoking was allowed, the correlation between air PAH concentrations and air nicotine concentrations was stronger in venues that did not use candles or incense (n = 18, Spearman 0.80; $P < 0.001$). Air nicotine concentration, establishment smoking status, type of establishment, vehicular traffic, use of candles or incense in the establishments were associated with increased indoor PAH concentrations (Table III). After adjustment for outdoor PAHs (tertiles),

TABLE II. Polycyclic Aromatic Hydrocarbons (ng/m^3) and Nicotine (μg/m^3) According to Establishment Characteristics, Santiago, Chile, 2010–2011

	Polycyclic aromatic hydrocarbons		Nicotine	
	Median	**(P_{25}–P_{75})**	**Median**	**(P_{25}–P_{75})**
PAH concentrations in establishment				
Inside establishment	113.0	(51.0–280.5)		
Outside establishment	71.0	(47.0–142.0)		
PAH concentrations by nicotine tertile				
Tertile 1	64.0	(30.0–129.0)		
Tertile 2	88.5	(56.0–147.0)		
Tertile 3	280.5	(113.0–449.0)		
Indoor concentrations by smoking status				
Smoking	152.0	(92.3–436.0)	3.72	(1.26–7.20)
Mixed				
Smoking area	83.5	(37.0–268.0)	2.43	(1.10–7.66)
Non-smoking area			1.10	(1.10–3.80)
Non-smoking	24.5	(19.0–129.0)	1.10	(1.10–1.10)
Outdoor concentrations by smoking status				
Smoking	79.0	(55.0–138.0)		
Mixed	83.8	(47.0–160.0)		
Non-smoking	49.0	(31.0–90.5)		
Indoor concentrations by traffic				
High	151.0	(90.0–283.5)	3.09	(1.10–4.82)
Medium	84.5	(28.5–228.5)	2.77	(1.10–6.89)
Low	28.0	(14.3–352.0)	1.32	(1.10–1.61)
Outdoor concentrations by traffic				
High	138.0	(66.0–174.0)		
Medium	56.5	(42.0–93.8)		
Low	44.5	(35.5–94.5)		
Type of establishment				
Bar/Pub	153.0	(94.5–449.0)	3.83	(1.67–9.98)
Restaurant	82.3	(27.5–240.5)	1.31	(1.10–4.06)
Surface area of establishment				
<100 m^2	94.5	(60.0–153.0)	1.15	(1.10–3.65)
>100 m^2	101.0	(30.0–280.5)	2.57	(1.10–8.29)
Unknown	258.0	(226.0–283.5)	4.08	(3.74–4.79)
Type of food sold in the establishment				
Full menu	81.0	(30.0–231.0)	1.55	(1.10–4.08)
Small dishes or no sale of food	238.0	(113.0–449.0)	3.87	(1.37–11.52)
Food preparation area isolated				
Yes, completely	94.0	(53.5–205.5)	1.66	(1.10–3.99)
Yes, partially	188.5	(46.0–449.0)	3.10	(1.10–11.55)
No	134.5	(19.0–250.0)	1.32	(1.10–1.54)
Type of stove				
Gas	113.0	(46.0–280.5)	2.57	(1.10–4.82)
No stove	319.5	(101.0–538.0)	4.69	(1.10–8.29)
Use of ventilation system				
No	88.5	(51.0–129.0)	1.37	(1.10–3.69)
Yes	146.5	(46.0–423.0)	3.34	(1.10–8.74)

(*Continued*)

TABLE II. (*Continued*)

	Polycyclic aromatic hydrocarbons		Nicotine	
	Median	(P_{25}–P_{75})	Median	(P_{25}–P_{75})
Type of ventilation				
Air conditioning				
No	226.0	(46.0–449.0)	3.74	(1.10–11.52)
Yes	94.5	(61.0–147.0)	1.64	(1.10–3.65)
Active extraction				
No	153.0	(46.0–449.0)	3.56	(1.10–8.29)
Yes	146.0	(61.0–226.0)	1.55	(1.10–9.98)
Fan				
No	73.8	(34.3–231.3)	1.37	(1.10–3.59)
Yes	240.5	(93.5–449.0)	7.98	(1.55–15.87)
Use of candles or incense				
No	91.8	(31.5–231.0)	2.50	(1.10–7.66)
Yes	667.0	(101.0–1978.5)	2.63	(1.10–3.74)

traffic (low/medium/high), use of candles (yes/no) and facility surface ($<100\,m^2$, $>100\,m^2$, unknown), PAH concentrations were 1.40 (0.64–3.10) and 3.34 (1.43–7.83) ng/m^3 higher for tertiles 2 and 3 of air nicotine compared to the lowest tertile.

DISCUSSION

The main sources of indoor PAH concentrations in bars and restaurants from Santiago were secondhand smoke, as measured by air nicotine, and the use of candles and incense. In venues were smoking was not allowed, indoor air concentrations of PAHs and nicotine were markedly lower compared to venues that allowed smoking, consistent with previous findings [Zhang et al., 2009]. These results confirm that secondhand tobacco smoke was a major source of PAHs emissions. Repace [Repace et al., 2006], for instance, reported that 85–95% of PAHs measured in the air of restaurants and bars can be attributable to secondhand tobacco smoke. In addition to smoking, we also found other relevant determinants of PAHs such as the use of burning candles and incense. While some determinants of indoor PAH concentrations are difficult to modify (e.g., outdoor traffic, size of the venue or ventilation systems), measures to eliminate smoking and maybe also the use of candles/incense could be implemented to reduce exposure to PAHs.

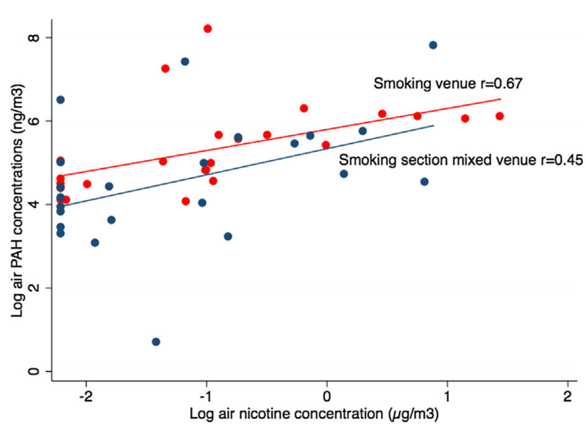

FIGURE 1. Correlation between polycyclic aromatic hydrocarbon (PAH) and nicotine concentrations in the air, according to smoking status of the establishment (smoking venue and mixed venue). Smoke-free establishments were not included in the figure because air nicotine concentrations were undetectable in 80% of establishments.

Restaurants and bars are spaces for eating and socializing; however, they are also work environments for the service personnel. SHS exposure remains a major problem among hospitality employees in countries around the world lacking comprehensive smoke-free legislation [Jones et al., 2013]. The health risk to which these workers are exposed is very high, as shown by a meta-analysis comparing air quality inside bars, office, and homes with at least one smoker, concluding that average SHS in bars is 3.9–6.1 times higher than in offices and 4.4–4.5 times higher than in the home of a smoker [Siegel, 1993]. The relationship between SHS exposure and risk of serious diseases including cancer, heart disease, and asthma is well established [Liu et al., 2014; Reijula et al., 2015]. This problem affects not only customers but especially the workers in restaurants and bars, whose passive exposure to tobacco smoke is prolonged and cumulative. Data indicates that exposure to tobacco smoke also increases the risk of short-term health effects inflammation of the eye conjunctiva and mucous membranes of the nose, throat, and inferior respiratory tract, with accompanying irritation, cough, and sore throat, which may affect work performance and compromise quality of life.

TABLE III. Geometric Mean Ratio (95% Confidence Interval) of Indoor Air Polycyclic Aromatic Hydrocarbons Concentrations by Air Nicotine Concentrations and Other Characteristics*

PAHs (ng/m^3)	Crude ratio (95% CI)	Adjusted ratio (95% CI)
Nicotine		
Tertile 1	1.00 (Ref.)	1.00 (Ref.)
Tertile 2	1.45 (0.60–3.49)	1.40 (0.64–3.10)
Tertile 3	3.26 (1.39–7.66)	3.34 (1.43–7.83)
Nicotine (natural log)	1.80 (1.31–2.49)	1.74 (1.25–2.44)
Outdoor PAH concentrations		
Tertile 1	1.00 (Ref.)	1.00 (Ref.)
Tertile 2	2.48 (0.95–6.43)	2.49 (1.11–5.59)
Tertile 3	2.18 (0.83–5.75)	1.37 (0.59–3.18)
Venue smoking status		
Non-smoking	1.00 (Ref.)	
Mixed	2.05 (0.75–5.64)	
Smoking	4.30 (1.58–11.75)	
Type of establishment		
Restaurant	1.00 (Ref.)	
Bar/Pub	2.74 (1.31–5.73)	
Vehicular traffic near venue		
Low	1.00 (Ref.)	1.00 (Ref.)
Medium	1.93 (0.45–8.32)	0.55 (0.26–1.16)
High	4.13 (0.95–17.99)	0.47 (0.13–1.71)
Air conditioning		
Yes	1.00 (Ref.)	
No	1.40 (0.53–3.71)	
Active air extraction		
Yes	1.00 (Ref.)	
No	1.36 (0.51–3.60)	
Candles or incense		
No	1.00 (Ref.)	1.00 (Ref.)
Yes	5.59 (2.41–12.9)	6.22 (2.55–15.21)
Venue surface area		
$<$100 m^2	1.00 (Ref.)	1.00 (Ref.)
$>$100 m^2	1.06 (0.47–2.37)	1.35 (0.64–2.85)
Unknown	3.11 (0.76–12.76)	1.32 (0.40–4.37)

*Linear regression model.
Air nicotine models were adjusted for outdoor PAHs (tertiles), vehicular traffic (low/medium/high), use of candles or incense (yes/no), surface area of establishment ($<$100 m^2, $>$100 m^2, unknown). Other variables were adjusted for all other variables as in the models for air nicotine concentrations in tertiles.

The use of candles or incense inside the establishments was associated with high PAH concentrations. When comparing the median between bar with or without use of candles or incense at the time of measurement we found that the use of candles or incense doubles the median of PAH of the bars without use of this products. In restaurants that used candles or incense at the time of measurement, PAH concentrations were 16 times higher compared to restaurants without use of candles or incense. After adjustment for other sources of PAHs including SHS and use of candles or incense, the air PAH concentrations were 6.22 (2.55–15.21) ng/m^3 higher in venues where these products were used. This finding is consistent with previous reports that detected sources of PAHs other than SHS inside restaurants [Hoh et al., 2012].

The presence of a fan was associated with higher PAH concentrations inside the venue, showing the inefficiency of the fan as a ventilation mechanism. It is important to note that a fan does not exchange air but merely circulates it. A study showed that combustion in kitchens increases environmental PAH concentrations and that it is therefore important to isolate the kitchen from the rest of the facility [Zhang et al., 2009]. Therefore, it is important to consider air quality in establishments that use lit candles and in areas in which different sources of combustion are used to prepare food, given the impact of these practices on workers and customers.

This study also measured the contribution of other sources of PAHs. Combustion of gasoline was examined by evaluating the influence of traffic flow outside of the establishments. Environmental PAH concentrations were also measured outdoors. We found that higher levels of PAHs were associated with a greater volume of vehicular traffic. This point is important given the high impact of the external environment on the air quality inside establishments, especially because these facilities tend to keep their windows and doors open as a ventilation mechanism.

Few studies have evaluated PAHs concentrations in hospitality venues around the world. To our knowledge, this is the first study to actively measure environmental PAHs and nicotine in the Latin American region. The quality of PAHs and nicotine measurements is one of the strengths of the study, as the methods ensure reliable and valid results by using calibrated equipment and specialized laboratory analyses. The use of nicotine, a specific biomarker of SHS is an important strength, as it is well-established air nicotine concentrations track very well with the number of cigarette smoked. Both PAHs and tobacco smoke in general are highly toxic to human health, especially for workers involuntarily and chronically exposed to these toxicants in their workplace.

The limitations of this study include the use of a nonrandom sample, which could affect the generalizability of the results; however, this study represents an adequate distribution of restaurants and pub/bar-type establishments in Santiago's five municipalities with the greater concentration of this type of facility. Willingness of owners or managers to participate might have biased the sample, with facilities in compliance with local sanitary and labor requirements being more likely to participate and more hazardous facilities being less likely to participate. This study was carried out between September 2010 and January 2011 (spring and early summer for Southern hemisphere), and therefore the use of ventilation systems and courtyards for outdoor eating might not reflect SHS and

PAHs exposure levels during the rest of the year. Previous studies have found that barbecue and Asian-style cooking are associated with high levels of indoor pollutants including PAHs [Zhu and Wang, 2003]. We did not specifically measure PAH concentrations in the kitchen and we did not collect information on the number of burners or specifically regarding frying, because our objective was to measure exposure to the workers and customers in the main customers areas. This lack of information could be seen as a limitation of our study, however we collected information on the type of burners and 100% of them were gas burners. Also none of the venues had barbeques or grills or served Asian-style food. In addition we collected information on the location of the kitchen to evaluate whether it was totally, partially or not at all isolated from the customers area. Most of the kitchens were totally (64.3%) and partially (32.1%) separated from the customer area. When the food preparation area was not at all isolated (3.6%) the PAH concentration was lower compared with a kitchen partially isolated. These results lead us to assume that the influence of PAHs generated in the kitchen may have less impact on the concentration of PAHs measured in the customer area. Another limitation of the study is related to the variability expect from day to day or shift to shift in the PAHs concentrations. We took the measures during the time of peak activity at the venues. Our mean sampling duration was 60 min (range 58–68), with half of the time being inside and half outside. Thirty minutes sampling is typical of studies assessing secondhand smoke exposure in hospitality venues using real time sampling devices [Avila-Tang et al., 2010; Apelberg et al., 2013]. The measure is likely to represent exposure levels happening during the times of peak activities in the venues (between 7 PM and midnight). Most of the measures were collected on Friday and Saturday. We conducted some comparisons for measures collected mid-day (n = 14, median 26, P_{25}–P_{75} 20.0–83.5 ng/m^3) versus the evening (n = 43, median 149, P_{25}–P_{75} 80.5–423 ng/m^3). By day of the week the concentrations ranged from 93.0 ng/m^3 on Thursdays to 143 ng/m^3 on Saturdays. We are aware that it would have been good to collect repeated measures in at least some venues, however do to logistic reasons and budget limitations we only went once to each venue.

In conclusion, this study showed that bars and restaurants in which smoking was allowed resulted in high PAH concentrations, including establishments with mixed smoking policies. The study also showed the inefficacy of currently used ventilation and isolation systems. At the date of this research, this study provided evidence that public health interventions regarding tobacco use remained insufficient in Chile, leaving hospitality workers vulnerable in all facilities where smoking was still allowed. Our study provides information on indoor PAH concentrations in hospitality venues and it can be informative to countries and subnational entities with a need to implement smoke-free legislation to comprehensively protect the health of non-smokers working in these environments.

AUTHORS' CONTRIBUTIONS

CM: Substantial contributions to the acquisition, analysis and interpretation of data, drafting the work, final approval of the version to be published. AD: Substantial contributions to the conception, design of the work and interpretation of data, revising it critically for important intellectual content, final approval of the version to be published. ME: Substantial contributions to the interpretation of data, final approval of the version to be published. PA: Substantial contributions to the conception and design of the work, revising it critically for important intellectual content, final approval of the version to be published. CO: Substantial contributions to the acquisition of data, drafting the work, final approval of the version to be published. JP: Substantial contributions to the acquisition and analysis of data, final approval of the version to be published. SM: Substantial contributions to the acquisition and analysis of data, final approval of the version to be published. NM: Substantial contributions to the conception of the work and interpretation of data, revising it critically for important intellectual content, final approval of the version to be published; AN: Substantial contributions to the design of the work, analysis and interpretation of data, revising draft critically for important intellectual content, final approval of the version to be published; agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. VI: Substantial contributions to the conception and design of the work, analysis and interpretation of data for the work; drafting the work, final approval of the version to be published, agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

ACKNOWLEDGMENTS

The authors would like to acknowledge employees, managers, and venue owners who agreed to participate in this study.

FUNDING

This study was supported by National Fund for Research and Development in Health FONIS, CONICYT—MINSAL, Research Grant #SA09I062. One of the authors was supported by the Flight Attendant Medical Research Institute (FAMRI), the Bloomberg Initiative to Reduce Tobacco Use, and from the U.S. National Cancer Institute (R03CA153959).

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

DISCLOSURE BY AJIM EDITOR OF RECORD

Steven Markowitz declares that he has no competing or conflicts of interest in the review and publication decision regarding this article.

REFERENCES

Aceituno P, Iglesias V, Erazo M, Droppelmann A, Orellana C, Navas-Acien A. 2010. [The work environment as a source of exposure to secondhand smoke: A study in workers of bars and restaurants of Santiago, Chile]. Rev Med Chil 138:1517–1523.

Agency for Toxic Substances and Disease Registry (ATSDR). 1995. Toxicological profile for Polycyclic Aromatic Hydrocarbons (PAHs). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Available from: http://www.atsdr.cdc.gov/toxprofiles/tp69.pdf

Apelberg BJ, Hepp LM, Avila-Tang E, Gundel L, Hammond SK, Hovell MF, Hyland A, Klepeis NE, Madsen CC, Navas-Acien A, Repace J, Samet JM, Breysse PN. 2013. Environmental monitoring of secondhand smoke exposure. Tob Control 22:147–155.

Avila-Tang E, Travers MJ, Navas-Acien A. 2010. Promoting smoke-free environments in Latin America: A comparison of methods to assess secondhand smoke exposure. Salud Publica Mex 52(Suppl 2): S138–S148.

Denissenko MF, Pao A, Tang M, Pfeifer GP. 1996. Preferential formation of benzo[a]pyrene adducts at lung cancer mutational hotspots in P53. Science 274:430–432.

EPA. 1992. Health effects of passive smoking: Assessment of lung cancer in adults and respiratory disorders in children, review draft. U.S. Washington, D.C.: Environmental Protection Agency.

Erazo M, Iglesias V, Droppelmann A, Acuna M, Peruga A, Breysse PN, Navas-Acien A. 2010. Secondhand tobacco smoke in bars and restaurants in Santiago, Chile: Evaluation of partial smoking ban legislation in public places. Tob Control 19:469–474.

Evans DE, Ku BK, Birch ME, Dunn KH. 2010. Aerosol monitoring during carbon nanofiber production: Mobile direct-reading sampling. Ann Occup Hyg 54:514–531.

Glantz SA, Parmley WW. 1991. Passive smoking and heart disease. Epidemiology, physiology, and biochemistry. Circulation 83:1–12.

Harrison RM, Johnston WR. 1985. Deposition fluxes of lead, cadmium, copper and polynuclear aromatic hydrocarbons (PAH) on the verges of a major highway. Sci Total Environ 46:121–135.

Hoh E, Hunt RN, Quintana PJ, Zakarian JM, Chatfield DA, Wittry BC, Rodriguez E, Matt GE. 2012. Environmental tobacco smoke as a source of polycyclic aromatic hydrocarbons in settled household dust. Environ Sci Technol 46:4174–4183.

Jones MR, Wipfli H, Shahrir S, Avila-Tang E, Samet JM, Breysse PN, Navas-Acien A, Investigators FBS. 2013. Secondhand tobacco smoke: An occupational hazard for smoking and non-smoking bar and nightclub employees. Tob Control 22:308–314.

Lewtas J. 2007. Air pollution combustion emissions: Characterization of causative agents and mechanisms associated with cancer, reproductive, and cardiovascular effects. Mutat Res 636:95–133.

Liu R, Bohac DL, Gundel LA, Hewett MJ, Apte MG, Hammond SK. 2014. Assessment of risk for asthma initiation and cancer and heart disease deaths among patrons and servers due to secondhand smoke exposure in restaurants and bars. Tob Control 23:332–338.

Marr LC, Grogan LA, Wohrnschimmel H, Molina LT, Molina MJ, Smith TJ, Garshick E. 2004. Vehicle traffic as a source of particulate polycyclic aromatic hydrocarbon exposure in the Mexico City metropolitan area. Environ Sci Technol 38:2584–2592.

MINSAL. 1995. Ley 19419. Regula actividades que indica relacionadas con el tabaco. Ministerio de Salud. Biblioteca del Congreso Nacional de Chile.

NIOSH, National Institute for Occupational Safety and Health. 1991. Current intelligence bulletin, intelligence bulletin #54: Environmental tobacco smoke in the workplace, lung cancer and, lung cancer and other health effects U.S. Cinncinati: Department of Health and Human Services.

National Research Council (NRC). 1986. Environmental tobacco smoke—Measuring exposures and assessing health effects. Washington, DC:National Academy Press. Available from: http://www.nap.edu/read/943/chapter/1

Pan American Health Organization. 2013. Informe sobre Control de Tabaco para la Región de las Américas Washington.

Reijula J, Kjaerheim K, Lynge E, Martinsen JI, Reijula K, Sparen P, Tryggvadottir L, Weiderpass E, Pukkala E. 2015. Cancer incidence among waiters: 45 years of follow-up in five Nordic countries. Scand J Public Health 43:204–211.

Repace JL, Hyde JN, Brugge D. 2006. Air pollution in Boston bars before and after a smoking ban. BMC Public Health 6:266.

Siegel M. 1993. Involuntary smoking in the restaurant workplace. A review of employee exposure and health effects. JAMA 270:490–493.

Surgeon general's report. Second hand smoke. 2006 [cited 2009 January 20th]; Available from: http://www.surgeongeneral.gov/library/secondhandsmoke/report/chapter10.pdf

Vardoulakis S, Chalabi Z, Fletcher T, Grundy C, Leonardi GS. 2008. Impact and uncertainty of a traffic management intervention: Population exposure to polycyclic aromatic hydrocarbons. Sci Total Environ 394:244–251.

WHO. 2003. Convenio Marco de la OMS para el Control del Tabaco. 56ª Asamblea mundial de la salud.

World Health Organization (WHO). 2004. International Agency for Research on Cancer Monographs on the evaluation of carcinogenic risks to humans. Tobacco smoke and involuntary smoking. Vol. 83. pp. 1–1473. Available from: http://monographs.iarc.fr/ENG/Monographs/vol83/mono83.pdf

Zhang B, Bondy S, Ferrence R. 2009. Do indoor smoke-free laws provide bar workers with adequate protection from secondhand smoke? Prev Med 49:245–247.

Zhu L, Wang J. 2003. Sources and patterns of polycyclic aromatic hydrocarbons pollution in kitchen air, China. Chemosphere 50: 611–618.