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Characterization and health risk assessment of $PM_{2.5}$-bound organics inside and outside of Chinese smoking lounges

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HIGHLIGHTS

- Although confining smokers to an enclosed area, ETS still migrates to indoor air for non-smokers.
- The ratio of BaP to BghiP is much higher in the smoking area, indicating the presence of ETS.
- The health risk to non-smokers outside of the smoking lounges did not exceed guidelines for the areas studied.

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ABSTRACT

$PM_{2.5}$ samples were collected at six indoor public places that contained dedicated smoking lounges. Samples were taken in the smoking lounges, at two indoor locations outside of the lounges, and in outdoor air near the venues. Organic carbon (OC), elemental carbon (EC), and non-polar organic compounds including polycyclic aromatic hydrocarbons (PAHs), *n*-alkanes (*n*-C_{16} to *n*-C_{40}), iso/anteiso-alkanes (C_{29} to C_{33}), hopanes and phthalate esters (PAEs) were quantified. Average $PM_{2.5}$ levels of 170.2 ± 85.9 μg/m^3 in the lounges exceeded limits of 25 μg/m^3 set by World Health Organization (WHO); these levels were 5.4 and 3.9 times higher than those indoors and outdoors, respectively. High ratios of OC to $PM_{2.5}$, OC to EC, and PAHs diagnostic ratios in the lounges indicated contributions from environmental tobacco smoke (ETS). The maximum carbon number (C_{max}) and carbon preference indices (CPI) for *n*-alkanes showed ETS transport from the enclosed lounges to nearby indoor non-smoking areas. Iso/anteiso-alkanes in the lounges were 876.5 ng/m^3, ~80 times higher than outdoor levels. 17α(H)-21β(H),30-norhopane and 17α(H)-21β(H),(22R)-homohopane were much higher in the lounges than outdoor air, but they cannot be directly attributed to ETS. Estimated carcinogenic risks of PAHs in the lounges exceeded the acceptable level of 10^{-6}.

1. Introduction

Environmental tobacco smoke (ETS) from cigarettes, cigars, pipes, and e-cigarettes contains a variety of gases and particles that are detrimental to public health (Kavouras et al., 1998; Bansal and Kim, 2016). Suspended particulate matter (PM), a major component of ETS, contains diverse compounds such as polycyclic aromatic hydrocarbons (PAHs), alkanes, and organonitrates that are

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genotoxic and carcinogenic (Rogge et al., 1994; Liang and Pankow, 1996). ETS elevates the risk of respiratory diseases and lung cancer for both of children and adults (Kim et al., 2014; Lee et al., 2016). ETS concentrations in entertainment venues are 2.4–18.5 times higher than those in office buildings (Siegel and Skeer, 2003), and increased nicotine metabolites in urine have been found for casino and other hospitality workers (Larsson and Montgomery, 2008; Achutan et al., 2009). Repace (2004) found that ETS generated 50 times more cancer-causing particles than those found along city streets and highways during rush-hour traffic. Acute ETS exposures degrade micro vascular functions (Adamopoulos et al., 2008). General (2010) concluded that exposures to low levels of ETS can increase endothelial dysfunction and inflammation.

Smoke-free policies in the workplace and other indoor public areas intend to reduce the number of smokers and ETS exposures (Bauer et al., 2005; Seo et al., 2011; MacNaughton et al., 2016). After implementation of a smoke-free workplace law (D-2002SFL) in Delaware, USA in 2002, $PM_{2.5}$ mass and $PM_{2.5}$-bound PAH concentrations decreased by factors of 20–40, from 205 μg/m^3 and 163 ng/m^3 to 9 μg/m^3 and 4 ng/m^3, respectively, in entertainment venues (Repace, 2004). Indoor smoking bans in public buildings (WHO, 2015) were introduced in eighteen Chinese megacities in 2014. However, smoking lounges, enclosed public areas such as shopping malls, entertainment venues, and airports, are exempt. Although air in the smoking lounge can be ventilated with enhanced circulation and/or filtration systems, this does not completely eliminate health risks from ETS exposure.

This study characterizes $PM_{2.5}$ (particles with an aerodynamic diameter less than 10 μm [μm]) from ETS inside and outside of six indoor smoking lounges in Hong Kong and Macau, Special Administrative Regions of China during 2016. Chemical profiles for organic carbon (OC), elemental carbon (EC), PAHs, *n*-alkanes, iso/anteiso-alkanes, phthalate esters (PAEs), and hopanes were measured. PAH diagnostic ratios, indices of *n*-alkanes, and pollutant ratios of smoking to non-smoking indoor areas (NSIA) were examined to evaluate similarities, differences, and potential source mixtures. Potential transport from smoking to non-smoking areas is investigated and health risks of PAHs and PAEs are assessed.

2. Methodology

2.1. Site description and sample collection

The six smoking lounges average 192 visitors per day and are used daily, seven days a week. Smoking outside the lounges is forbidden and monitored by security guards. Other pollution within the larger indoor areas derives from outdoor air infiltration, dust raised by foot traffic, and cleaning/maintenance activities. Four sampling locations were selected for each venue, including: a) inside the smoking lounge (SL), b) 2 m from the SL entry/exit ($NSIA_{2m}$), and c) 5 m from the SL entry/exit ($NSIA_{5m}$), and d) outdoor air (~25 m from the venue). Table 1 summarizes the smoking lounge characteristics.

Two collocated $PM_{2.5}$ samples were collected onto quartz-fiber filters (47 mm, QMA, Whatman, Clifton, NJ, USA) using mini-volume air samplers (Airmetrics, Eugene, OR, USA) at a flow rate of 5 L/min for 24 h (from 08:00 to 07:59 local standard time next day). Four samples were collected at each of the entertainment venues' four sampling locations with a total of 96 samples for the six venues.

Before sampling, filters were pre-fired (780 °C, 3 h) to remove adsorbed organic vapors. $PM_{2.5}$ mass were obtained by gravimetry using a Sartorius ME 5-Felectronic microbalance (±1 μg sensitivity; Sartorius, Göttingen, Germany). Each filter was weighed at least two times before and after sampling which were equilibrated at temperature (22 ± 2 °C) and relative humidity (RH, 35–45%) controlled room. The maximum differences between the replicates were <15 and < 20 μg, for blank and loaded filters, respectively. To prevent any loss of volatiles, samples were packed in pre-baked aluminum foil and stored in a freezer at −20 °C.

Table 1
Summary of smoking lounge[a] characteristics.

	Indoor Public Places					
	I	II	III	IV	V	VI
Smoking lounge area (m^2)	6	50	23	20	12	50
No. of people accessing per hour	5	1	10	12	6	16
Door openings per hour	10	5	20	20	10	30

[a] The smoking lounges sampled are not identified due to a privacy agreement.

2.2. Carbonaceous aerosol analyses

OC and EC were quantified on a 0.53 cm^2 punch from each sample with a DRI model 2001 thermal/optical carbon analyzer (Atmoslytic, Inc., Calabasas, CA, USA) following the IMPROVE_A thermal/optical reflectance protocol (Chow et al., 1993; Ho et al., 2004; Cao et al., 2007; Chow et al., 2007). The IMPROVE_A protocol produces four thermal OC fractions, OC1, OC2, OC3, and OC4 at 140, 280, 480, and 580 °C, respectively, in a pure helium [He] atmosphere. Three thermal EC fractions, EC1, EC2, and EC3 at 580, 740, and 840 °C, respectively, are obtained in a 2% oxygen (O_2)/98% He atmosphere. A pyrolyzed carbon fraction, OP, is determined when reflected laser light attains its original intensity after O_2 is added to the carrier gas. OC is defined as the sum of the four OC fractions (OC1-OC4) plus OP, and EC is defined as the sum of the three EC fractions (EC1-EC3) minus OP to account for conversion of OC to EC by pyrolysis.

2.3. Non-polar organic speciation analysis

Non-polar organic compounds were quantified, including PAHs, *n*-alkanes (*n*-C_{14} to *n*-C_{40}), iso/anteiso-alkanes, hopanes and PAEs, using in-injection port-thermal desorption-gas chromatography-mass spectrometry (TD-GC/MS) (Ho and Yu, 2004; Ho et al., 2008). Filter sections (0.53–2.63 cm^2) were inserted into a TD tube for insertion into the GC injector port at 50 °C. The temperature was then raised to 275 °C for desorption in a splitless mode while the GC oven temperature was kept at 30 °C. After the injector temperature reached the set point, the oven program started. The mass spectrometer detector was full-scanned from 50 to 650 amu under electron impact ionization (EI) at a voltage 70 eV and ion source temperature of 230 °C. Identification was achieved by associating characteristic ion fragments and peak retention times with those of standards. Field blank filters were analyzed using the same procedures.

2.4. Health risk assessment

ETS exposure changes aortic waveforms and weakens microvascular function, even after exposure ends (Argacha et al., 2008). A 12% decrease in heart rate variability from ETS exposures of non-smoking adults to a 53 μg/m^3 increment of $PM_{3.0}$ in a commercial airport was reported by Pope et al. (2001). This was interpreted by Repace et al. (2011) as a 12% increase in cardiac mortality risk, which translates to ~2.3% per 10 μg/m^3 increase in $PM_{3.0}$.

Health risks are estimated from PAH and PAE lifetime average daily doses (LADD) through PM inhalation (Li et al., 2013; Ma et al., 2014; Kong et al., 2015). The incremental lifetime cancer risk (ILCR)