Chemosphere 205 (2018) 45–51

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Factors affecting ambient endotoxin and particulate matter concentrations around air vents of subway stations in South Korea

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HIGHLIGHTS

- We assessed factors affecting airborne endotoxin levels around subway air vents.
- Eight locations were sampled for endotoxins and PM for over a year in Seoul.
- Endotoxin levels were highest in fall and had patterns similar to airborne bacteria.
- Levels in vents with glass walls and locations that allowed smoking were higher.
- Installing barriers on vents may lessen exposure to endotoxins.

ARTICLE INFO

Article history:
Received 15 January 2018
Received in revised form
9 April 2018
Accepted 13 April 2018
Available online 14 April 2018

Handling Editor: R Ebinghaus

Keywords:
Air vent system
Subway station
Endotoxins
Particulate matter
Smoking
South Korea

ABSTRACT

Levels of airborne endotoxins and particulate matter less than 10 μm and 2.5 μm in diameter (PM) were measured in the air vents of subway stations in Seoul, South Korea, and factors affecting both pollutants were analyzed. The measurements were completed from March 2016 to February 2017 for eight air vents situated at the ground level around the subway stations. A total of 166 air samples were collected and analyzed using the kinetic limulus amebocyte lysate assay. Endotoxin levels ranged from not detected to 1.986 EU m^{-3}, with a mean of 0.227 EU m^{-3}. The results showed significantly different PM levels from the measurements reported by AIRKOREA as part of the comprehensive air quality index. This can be attributed to different sampling sites in the same area. Endotoxin levels tended to be higher in fall compared to summer. Airborne bacteria levels showed a pattern similar to the endotoxin levels, but no significant association was reported between them. The levels of endotoxins around air vents with a glass cover and streets that allowed smoking were significantly higher than those not containing a walled barrier and streets in which smoking was prohibited. Multivariate regression analysis showed that the factors affecting endotoxin levels comprised air vents with a glass cover (coefficient = 0.106, $p = 0.014$) and season (coefficient = 0.062, $p < 0.0001$). Therefore, installing barriers on the air vents and prohibiting smoking in streets to which the vents open may be effective ways to lessen exposure to airborne endotoxin levels around air vents.

1. Introduction

By law, South Korea requires the monitoring of various types of air pollutants, such as particulate matter (PM) of diameters of 10 μm or less and of 2 μm or less (PM_{10} and $PM_{2.5}$, respectively), carbon monoxide, nitrogen dioxide, sulphur dioxide, and ozone (Ministry of Environment, 2017). Although airborne endotoxins can cause respirable health effects, they have not been measured in outdoor environments as the law does not mandate their monitoring. Endotoxins, which are lipopolysaccharides, are ubiquitous in the environment and are an important structural component of the outer membrane of Gram-negative bacteria (Beutler and Rietschel, 2003). Exposure to endotoxins has been found to cause and exacerbate asthma and wheezing in both children and adults (Abbing-Karahagopian et al., 2012). Endotoxins have also been implicated in

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https://doi.org/10.1016/j.chemosphere.2018.04.072
0045-6535/

the impairment of lung function (Liebers et al., 2008), the pathogenesis of pulmonary diseases (Loh et al., 2006), and acute lung injury (Thorn, 2001). According to a recent study, they can lead to dramatic changes in the number of white blood cells in the body, thus impairing immune function (Shang et al., 2016).

Among various kinds of public environments, subways are major public transportation systems in cities worldwide, including Seoul. They are used by people of various ages, from children to senior citizens (Hwang et al., 2017a,b). PM levels in underground subway stations have been reported to evaluate the effects of tunnel ventilation at platforms (Moreno et al., 2017), the relationship between PM levels and multivariate factors (Kwon et al., 2015), PM levels in subway cabins (Cheng et al., 2012; Kim et al., 2014; Grana et al., 2017; Zheng et al., 2017). However, PM levels at air vents situated outside subway stations have never been studied. Moreover, assessments of endotoxin levels have been reported using only surface samplers at subway stations, but these are insufficient for analyzing the influence of factors, especially those of various pollutants (Dong and Yao, 2010).

Air vents of subway stations are part of the ventilation system wherein the indoor air of the subway station exhausts to the outside and clean air is exchanged. There are 1849 air vents located around subway stations in Seoul. It is natural to be concerned about the functioning of the air vents because many people, including sensitive populations, are exposed to them. Thus, measuring levels of endotoxins and PM levels around air vents is important to understand the concentrations and distributions of these pollutants on public streets as well as to undertake appropriate interventions to protect sensitive populations.

In this study, the levels of airborne endotoxins and PM were measured around eight selected air vents of subway stations in Seoul, to determine which factors (namely, temperature, relative humidity (RH), weather conditions, season, smoking in the vicinity, and air vent characteristics) might influence these levels. This study was conducted over a period of one year.

2. Method

2.1. Characteristics of the air vent

The air from inside the underground subway station flows to the outside (street) via air vents containing a filter. Table 1 summarizes the characteristics of the air vents around subway stations. In terms of the structure, we categorized the vents as those containing a glass cover and those without, to assess if this factor affected endotoxin levels. Eight air vents around subway stations were randomly selected and monitored (two air vents each for lines 1, 2, 3, and 4).

2.2. Sampling endotoxins, PM_{10} and $PM_{2.5}$

We collected samples from the air vents around subway stations in spring, summer, autumn, and winter (from March 2016 to February 2017). A total of 166 air samples were collected on regular working days. The samples were taken at a height of 100–150 cm above the air vent. During the endotoxin sampling, temperature and RH were recorded from each spot using a Unis digital thermometer (YTH-104 Series, Unis Inc., Korea). Samples were collected using an air sampler (17G9 Gil Air Sampler, Gilian Sensidyne, Inc., U.S.A.) with glass fiber filters (diameter, 37 mm; SKC Inc., U.S.A.) at a flowrate of 2.0 L min^{-1} (±5%) for an average of 6 h using an Escort ELF Pump (Mine Safety Appliances Company, Pennsylvania, U.S.A.). The samples were stored at 4 ± 2 °C, sent to an analytical laboratory within a week of sampling, and analyzed immediately upon arrival. Detection and quantitation of endotoxin levels were conducted using the kinetic-turbidimetric Limulus Amebocyte Lysate (LAL) assay (Associations of Cape Cod, Inc., U.S.A.). The entire endotoxin extraction procedure was conducted at room temperature (25 ± 2 °C). Fifteen mL of extracted pyrogen-free water was added to a test tube, which was then capped and sonicated at a minimum peak frequency of 48 kHz for 1 h (ASTM, 2007). Next, the samples were centrifuged at 1000 g for 15 min and the supernatant was transferred to a pyrogen-free test tube. One hundred milliliters of each sample was distributed into a pyrogen-free 96 well microplate and incubated at 37 °C for 10 min in an automated microplate reader (Bio TekELx808, BioTek Instruments, U.S.A.). One hundred milliliters of LAL reagent was added to each well and analyzed twice at 340 nm using WinKQCL Software (Bio Whittaker, Cambrex Co., U.S.A.). *Escherichia coli* O55:B5, the control standard endotoxin (Lonza, U.S.A), was utilized to draw a standard curve ranging from 0.005 to 50 EU mL^{-1}. Only samples having calibration curves with a WinKQCL value of 0.98 or greater were accepted for further analysis. As part of the validation studies, positive product control (PPC) recoveries were within 50–200% and the coefficients of variation were set to less than 10%. The endotoxin levels were expressed as endotoxin unit per cubic meter of air (EU m^{-3}). The assay limit of detection (LOD) was 0.01 EU mL^{-1} of extract. Values below the LOD were assigned a value of $\frac{LOD}{\sqrt{2}}$ (Hornung and Reed, 1990).

2.3. Comparing samples PM_{10} and $PM_{2.5}$ data with PM measurements from AIRKOREA

PM samplers were deployed for seven air vents from January to February 2017. PM levels were sampled using a DustMate sampler (Turnkey Instruments Ltd., U.K.) at a flow rate of 600 cc/min for 6 h at 5-min intervals. The inlets of the PM sampler were located

Table 1
Characteristics of the eight sampled subway station air vents.

Station	No. of samples	Mean ± SD		Air vent		Structure of the air vent	Station characteristics
		Temperature (°C)	Relative Humidity (%)	Area (m^2)	Height (m)		
A	4	22.4 ± 6.6	23.8 ± 1.7	10.7	1.1	With a glass cover	Located between an eight-lane road and a shopping district
B	22	18.7 ± 10.8	42.4 ± 15.4	16.0	0.4	With a glass cover	Located between a nine-lane road and shopping district
C	24	18.5 ± 10.4	40.9 ± 14.3	25.9	0.9	With a glass cover	Located between a ten-lane road and shopping district
D	23	17.9 ± 10.4	38.0 ± 14.2	11.8	1.4	No wall	Located between a six-lane road and shopping district
E	22	23.3 ± 7.7	37.8 ± 17.4	24.3	1.2	No wall	Located between an eight-lane road and a shopping district
F	24	20.4 ± 10.5	42.8 ± 15.0	32.1	2.0	With a glass cover	Located in between an eight-lane road and a one-lane road
G	23	16.1 ± 12.5	38.9 ± 13.7	14.3	0.3	With a glass cover	Located in between a seven-lane road and a shopping district
H	24	22.7 ± 8.9	42.3 ± 16.0	9.2	1.2	No wall	Located in between a five-lane road and a shopping district
Total	166	20.0 ± 9.7	38.4 ± 13.5				