보건학석사 학위논문

Effects of Outdoor Smoke-Free Policy at Bus Stops on Outdoor Tobacco Smoke Exposure in Seoul

서울시 실외 금연정책 실시와 버스정류장에서의 간접흡연

2013년 2월

서울대학교 보건대학원

환경보건학과 환경보건 전공

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Abstract

Effects of Outdoor Smoke-Free Policy at Bus Stops on Outdoor Tobacco Smoke Exposure in Seoul

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The Seoul Metropolitan government implemented an outdoor smoke-free policy at centerline bus stops from December 2011 and began imposing fines for smoking at these bus stops from March 1, 2012. Although significant improvement in indoor air quality due to indoor smoke-free policy has been well documented, impact of outdoor smoke-free policies has not been established. The objectives of this study were to determine the levels of compliance with the outdoor smoke-free policy and to identify the factors associated with outdoor $PM_{2.5}$ concentrations at the bus stops in Seoul.

This study was conducted at 100 bus stops including 50 centerline bus stops (located in the middle of main streets) and 50 roadside bus stops in Seoul, Korea. Smoking was observed and $PM_{2.5}$ concentrations were measured at the same locations in autumn 2011 and spring 2012. Using real-time aerosol monitor, $PM_{2.5}$ was measured for 30 minutes at 1-second

intervals. Because ambient air pollutants can fluctuate rapidly due to environmental conditions, a ‘peak analysis’ method was developed to determine the outdoor $PM_{2.5}$ exposure from cigarette smoke. Using the newly established definition of ‘peak’, the peak frequency (number of peaks per hour) and peak concentration were determined at each bus stop.

The occurrence of smoking at 100 bus stops in Seoul was observed before and after the implementation of the smoke-free policy. Smoking was observed at 46% and 37% of the 100 bus stops before and after the implementation of the smoke-free policy, respectively. At the centerline bus stops where the policy was applied, smoking occurrence was decreased by 75% after implementation of the smoke-free policy. However, at roadside bus stops where the policy was not applied, smoking was observed at 76% and 70% of the bus stops before and after the policy, respectively.

The peak analysis indicated that the $PM_{2.5}$ peak frequency was significantly associated with the bus stop location, season, occurrence of smoking, and the number of buses servicing a route. The $PM_{2.5}$ peak concentrations were significantly associated with season, occurrence of smoking, and the number of buses servicing a route. Smoker status was categorized as standing or walking-through, and peak concentrations at bus stops were significantly higher with standing smokers than with walking-through smokers. Higher peak $PM_{2.5}$ concentrations were recorded when smokers were positioned closer to the monitor. For standing smokers, peak frequency decreased with increasing distance from the monitor, but this effect was not significant.

This study found non-compliance with the outdoor smoke-free policy at centerline bus stops in Seoul. More people smoked at roadside bus stops where the policy was not applied. The Smoke-free policy should be applied to both centerline and roadside bus stops to reduce outdoor tobacco smoke exposure at bus stop in Seoul. The $PM_{2.5}$ peak frequency and peak concentrations were significantly associated with the occurrence of smoking, smoker status, and distance from the smoker to the monitor. Further research using 'peak analysis' is needed to measure smoking-related exposure to fine particulate matter in other outdoor locations.

Keywords : Smoking-free policy, Outdoor, $PM_{2.5}$, Bus stop, Peak

Student Number : 2011-22059

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I. Introduction

Secondhand smoke (SHS) is the mixture of main stream and side stream smoke contained more than 7,000 chemicals and approximately 70 carcinogens (U.S. Department of Health and Human Services, 2006). Exposure to SHS presents serious health risks, such as asthma, respiratory disease, and lung cancer, to those who inhale the various harmful toxins (Eriksen *et al.*, 1988; U.S. Department of Health and Human Services, 2010). SHS has also been reported to have a role in causing ischemic heart disease (Wells, 1994). In some recent studies, adverse health outcomes in both children and adults have reported. The relationship between SHS exposure and a reduction in the cognitive ability of children has been shown (Yolton *et al.*, 2005). In addition, increased levels of respiratory disease in adults exposed to SHS in work environments and an increased incidence of cancer in people who have been exposed to SHS in their childhood homes have been reported (Vineis *et al.*, 2005).

To protect the health of citizens and workers, indoor smoke-free policies and laws have been implemented by various countries, states and municipalities (Lee *et al.*, 2009). Significant improvements in indoor air quality have been reported after the implementation of indoor smoke-free policies. For example, indoor $PM_{2.5}$ concentrations immediately decreased by decreasing 79% following the implementation of an indoor smoke-free policy in Georgetown, Kentucky, USA (Lee *et al.*, 2007). In Scotland, indoor $PM_{2.5}$ concentrations were reduced by 92% after smoke-free legislation was implemented (Semple *et al.*, 2007). Following an indoor smoking ban in Italy, $PM_{2.5}$ levels decreased significantly from 119.3 $\mu g/m^3$ to 38.2 $\mu g/m^3$ (Valente *et al.*, 2007).

When SHS occurs outdoors, it is referred to as outdoor tobacco smoke (OTS). OTS can be as dangerous as indoor SHS depending on the specific environmental conditions such as the weather, wind speed, wind direction, and temperature (Repace, 2000). Some countries including the United States, Australia, and New Zealand have addressed the health threat from OTS by implementing outdoor tobacco-free areas such as at college campuses, outdoor stadiums, parks, and beaches (Klein *et al.*, 2007; Lee *et al.*, 2010).

As of 2012, 85 of 244 local governments in Korea prohibit outdoor smoking in some public places such as main streets, parks, and children's playgrounds. The Seoul metropolitan government began enforcing an outdoor smoking policy to reduce OTS exposure in public places on March 1, 2011, which has subsequently been gradually expanded. Since December 2011, 295 centerline bus stops which located in the center of main roads have been designated as non-smoking areas by the city council. Roadside bus stops in Seoul are expected to be designated as non-smoking areas in 2014.

In Seoul, bus stops are located in the middle, or on the side, of main roads. Bus stops are public places where people can board or disembark a bus safely. People who are sensitive to respiratory disease such as infants and the elderly as well as non-smokers may use bus stops. Because bus stops are located close to roads with high traffic volumes, passengers can be exposed to hazardous substances contained in automobile exhaust gas, including particulate matter less than 2.5 μm aerodynamic diameter ($PM_{2.5}$) (Gertler *et al.*, 2000; Westerdahl *et al.*, 2005). When smoking occurs at bus stops, people may be exposed to an additional $PM_{2.5}$ burden from burning cigarettes (Hess *et al.*, 2010).

Although indoor smoke-free regulations have significantly improved indoor air quality, the effects of outdoor smoking policies have not been documented (Parry *et al.*, 2011; Repace, 2007). Because there is a lack of published OTS monitoring data, the debate over the validity of outdoor smoking policies is ongoing (Klepeis *et al.*, 2007). The objectives of this study were to determine whether the implementation of an outdoor smoke-free policy at bus stops in Seoul has been effective and to identify the factors that influence $PM_{2.5}$ concentrations at bus stops.

II. Methods

2.1 Sampling sites

This study was conducted at 100 bus stops in Seoul, Korea. Measurements were made at 50 centerline bus stops and 50 roadside bus stops. A bus stop was considered to extend for 10 m to either side of the bus stop sign because the length of a typical bus was 10 m. The bus stops were purposely selected to be well distributed throughout the city. $PM_{2.5}$ concentrations were measured in the period between 7:00 AM and 8:00 PM on weekdays, which included the business rush hours. The first measurement was conducted in November 2011. The outdoor smoke-free policy at centerline bus stops was implemented on December 1, 2011. The $PM_{2.5}$ concentrations were measured again at the same locations in March 2012, after the city council began imposing fines for violation of the outdoor smoke-free policy.

2.2 $PM_{2.5}$ measurement

The $PM_{2.5}$ concentration was measured using a Sidepak aerosol monitor (Model AM510, TSI Inc., MN, USA), which consists of a portable nephelometer with a 2.5 μm impactor. The equipment was used for stationary monitoring and recorded real-time PM levels as mass concentration data. At both centerline and roadside bus stops, the aerosol monitor was set on a tripod adjacent to the bus stop sign at a height of 1.5 m. Prior to each measurement, the monitor was zero-calibrated with a HEPA filter and the air flow rate was set to 1.7 L/min. $PM_{2.5}$ concentrations were measured every second over a 30-minute period at each sampling site. The measured value was corrected by a conversion factor of 0.295 obtained from a calibration against a gravimetric measurement (Lee *et al.*, 2008).

During aerosol monitoring, specific factors related to $PM_{2.5}$ levels were investigated at each bus stop, i.e., rush hour or non-rush hour, location of bus stop (centerline or roadside), number of lanes, number of buses servicing a route, occurrence of smoking, numbers of smokers, and distance between smokers and the monitor. Temperature and relative humidity at each location were measured at 5-minute intervals using a thermo-hygrometer (Model U10, Onset, MA, USA).

2.3 Peak analysis

Because ambient air pollutants can rapidly fluctuate due to environmental and physical conditions such as wind direction and wind speed, a new analytical method called ‘peak analysis’ was developed to determine outdoor $PM_{2.5}$ exposure from cigarette smoke. Although several previous studies have used the term ‘peak’ (Buonanno *et al.*, 2011; Cameron *et al.*, 2010), it has not been clearly defined. In this study, ‘peak’ was defined as a point where the concentration difference in 1 second (C_i - C_{i-1}) was greater than 35 $\mu g/m^3$. The selection of 35 $\mu g/m^3$ for defining the peak was determined by the distribution of the difference between C_i and C_{i-1} at bus stops where no smoking occurred. Although the 99.5 percentile of the distribution was 33 $\mu g/m^3$, 35 $\mu g/m^3$ was selected because this value is the 24-hour US National Ambient Quality Standards for $PM_{2.5}$. When there was more than one peak within a 9-second period (C_{i-4} ~ C_{i+4}), the maximum concentration within the 9-second interval was selected as a peak. Nine seconds was considered to represent the time taken for one puff of cigarette smoke and was evenly divided before and after a peak. The peak frequency (number of peaks per hour) and average peak level were calculated for each bus stop.

2.4 Statistical analysis

Using the field observational data, the occurrences of smoking before and after the smoke-free policy were compared to determine the levels of compliance with the smoke-free policy at centerline bus stops. Using the 30-minute integrated concentrations at each bus stop, statistical significance was tested for each factor that was considered to affect the $PM_{2.5}$ concentrations. Categorical data, such as the season, location of bus stop, rush hour or non-rush hour, and occurrence of smoking, were examined using Student's t-test. The number of buses servicing a route and the number of lanes were examined using Student's t-test and analysis of variance (ANOVA), respectively, after being classified into cumulative distribution groups. Using significant variables identified in the univariate analysis, a multiple regression analysis was conducted to identify factors associated with the average $PM_{2.5}$ concentrations at bus stops.

Descriptive 'peak analysis' results were determined. Because $PM_{2.5}$ peak concentrations were non-normally distributed, a natural log-transformation (ln-transformation) was applied to the peak concentrations. Using the $PM_{2.5}$ peak frequency and ln-transformed peak concentrations, a Student's t-test was conducted by season, location of bus stop, rush hour or non-rush hour, and occurrence of smoking. ANOVA was conducted using the peak frequency and ln-transformed peak concentration for the number of buses servicing a route and the number of lanes. The factors associated with $PM_{2.5}$ peak frequency and concentrations at bus stops were determined by multiple regression analysis using the significant variables identified in the univariate analysis.

To determine exposure to peak $PM_{2.5}$ levels from standing at the bus stop, a statistical analysis was conducted by smoker status. Smoker status was classified by observation into either standing at the bus stop or walking-through the bus stop. The relationship between the distance from a smoker to the monitor was determined using standing smokers. The effect of the number of smokers was also identified. The SAS 9.3 statistical package (SAS Institute Inc., Cary, NC, USA) was used for statistical analysis and graphs were drawn in SigmaPlot 10.0 (Systat Software Inc., San Jose, CA, USA).

III. Results

3.1 Observation of smoking at bus stops

The occurrence of smoking at 100 bus stops in Seoul was observed before and after the implementation of the smoke-free policy at centerline bus stops. Table 1 shows the occurrence of smoking at 50 centerline bus stops and 50 roadside bus stops. Smoking was observed in 46% and 37% of the 100 bus stops before and after the implementation of the smoke-free policy, respectively. Before implementation of the policy, smokers were observed at 16% of the 50 centerline bus stops and 76% of the 50 roadside bus stops. After policy implementation, smokers were observed at only 4% of the 50 centerline bus stops. However, smoking was still found at 70% of the 50 roadside bus stops.

Table 1. The occurrence of smoking at bus stops in Seoul before and after the implementation of the outdoor smoke-free policy

	N	Before policy	After policy
		Autumn 2011	Spring 2012
Centerline bus stop	50	8	2
Roadside bus stop	50	38	35

3.2 $PM_{2.5}$ exposure at bus stops

Outdoor $PM_{2.5}$ concentrations were measured twice at the same bus stops. The average $PM_{2.5}$ concentration for all bus stops was 26.0 ± 14.7 µg/m^3. The average $PM_{2.5}$ concentrations were 20.0 ± 11.8 µg/m^3 in autumn 2011 and 31.9 ± 14.9 µg/m^3 in spring 2012. The $PM_{2.5}$ concentrations in spring were significantly higher than in autumn (p<0.0001). Outdoor PM_{10} concentrations in the Seoul metropolitan area were available from the Seoul city government (http://cleanair.seoul.go.kr/). During the monitoring period, average ambient PM_{10} concentrations in Seoul were 41.6 ± 5.8 µg/m^3 in autumn 2011 and 57.6 ± 7.6 µg/m^3 in spring 2012. The average temperatures were 19.8 ± 5.3℃ in autumn 2011 and 21.7 ± 3.2℃ in spring 2012. The average relative humilities were 30.4 ± 7.6% in autumn 2011 and 33.2 ± 11.2% in spring 2012.

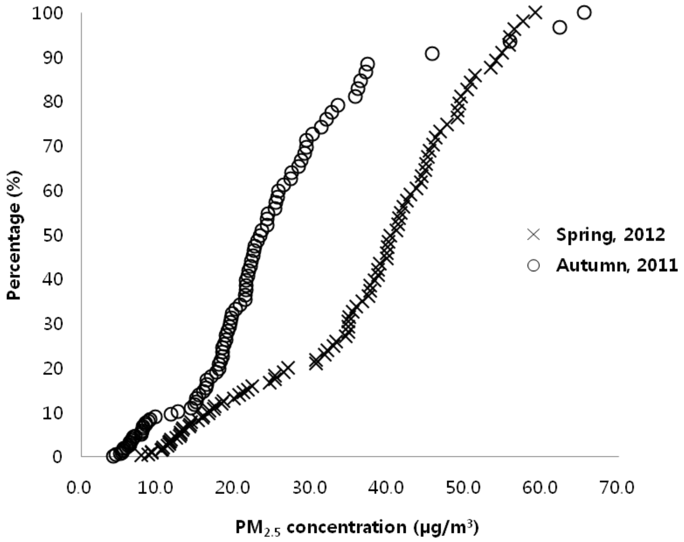

Figure 1. Cumulative frequency of $PM_{2.5}$ concentrations by season.

Univariate analysis revealed that several variables were significantly associated with 30-minute average $PM_{2.5}$ concentrations at bus stops (see Table 2). Average $PM_{2.5}$ concentrations at bus stops varied significantly between seasons and bus stop locations. Average $PM_{2.5}$ concentrations were significantly higher in centerline bus stops than in roadside bus stops (p=0.0043). However, average $PM_{2.5}$ concentrations did not vary significantly with time (p=0.4268), occurrence of smokers (p=0.1856), number of buses servicing a route (p=0.0642), or number of lanes (p=0.5627).

Table 2. Results of the univariate analysis for 30-minute integrated $PM_{2.5}$ concentrations at bus stops

Variable	Mean ± SD (μg/m^3)	SE	95% CI	*p*-value
Season				
Spring	31.9 ± 14.9	1.5	(28.9, 34.8)	<.0001
Autumn	20.0 ± 11.8	1.2	(17.7, 22.4)	
Bus stop location				
Centerline	28.7 ± 15.3	1.5	(25.6, 31.8)	0.0043
Roadside	23.3 ± 13.5	1.4	(20.6, 25.9)	
Time				
Non-rush hour	25.8 ± 14.7	1.2	(23.4, 28.2)	0.4268
Rush hour	26.3 ± 14.8	2.0	(22.2, 30.3)	
Smoking				
Smoking	24.8 ± 14.4	1.6	(21.7, 28.0)	0.1856
Non-smoking	26.7 ± 14.8	1.4	(24.0, 29.5)	
Number of buses servicing a route				
1–10	24.2 ± 13.8	1.5	(21.2, 27.1)	0.0642
11–21	27.4 ± 15.2	1.4	(24.5, 30.2)	
Lanes				
<4	24.2 ± 13.2	2.1	(20.0, 28.4)	0.5627
4	27.1 ± 15.2	1.6	(23.9, 30.2)	
>4	25.8 ± 15.1	1.8	(22.2, 29.4)	

SE: Standard error

Using the significant variables identified in the univariate analysis, multiple regression analysis was conducted. The significant variables for average $PM_{2.5}$ concentration were the season and bus stop location. Table 3 presents the results of the multiple regression analysis. The average $PM_{2.5}$ concentration at bus stops varied significantly between seasons and between bus stop locations. In spring, the $PM_{2.5}$ concentration was significantly higher than in autumn (p<0.0001). The centerline bus stops had a higher $PM_{2.5}$ concentration than the roadside bus stops (p=0.0041).

Table 3. Multiple regression analysis by a general linear model for 30-minute integrated $PM_{2.5}$ concentrations

Variable	β	SE	95% CI	p-value
Intercept	34.6	1.6		<.0001
Season				
Spring (reference)				
Autumn	-11.8	1.9	(-15.5, -8.1)	<.0001
Bus stop location				
Centerline (reference)				
Roadside	-5.4	1.9	(-9.1, -1.7)	0.0041

β: Regression coefficient

SE: Standard error

3.3 Short-term exposure to $PM_{2.5}$ at bus stops

A ‘peak analysis’ was conducted to identify the exposure to $PM_{2.5}$ from outdoor tobacco smoking. The average $PM_{2.5}$ peak frequency was 15.0 ± 19.4 peak/hr and the geometric mean of peak concentration was 87.6 $\mu g/m^3$ (geometric standard deviation: GSD=1.5). The peak frequencies were 13.0 ± 19.8 peak/hr in autumn 2011 and 17.1 ± 18.8 peak/hr in spring 2012. The geometric means of the peak concentration were 83.3 $\mu g/m^3$ (GSD=1.6) in autumn 2011 and 90.7 $\mu g/m^3$ (GSD=1.4) in spring 2012. $PM_{2.5}$ peak frequency and peak concentration in spring were significantly higher than the corresponding values in autumn (p=0.0356 for peak frequency and p=0.0253 for peak concentration).

The results of the univariate analysis of peak frequency and peak concentration are shown in Table 4. At centerline bus stops, the peak frequency was 18.2 ± 22.8 peak/hr and the peak concentration was 87.8 $\mu g/m^3$ (GSD=1.4). Peak frequency at centerline bus stops was significantly higher than at roadside bus stops (p=0.0132), but peak concentration was not significantly higher (p=0.4271). At bus stops where smoking occurred, the peak frequency and peak concentration were significantly higher. The geometric mean of peak concentration at bus stops where smoking occurred was 110.6 $\mu g/m^3$ (GSD=2.0), which was 24.5 $\mu g/m^3$ higher than the level at bus stops with no smokers (p<0.0001). The difference in the peak concentrations between bus stops where smoking occurred and non-smoking bus stops was greater than the difference for all the other variables. Peak frequency and peak concentration were significantly higher when there were more buses servicing a route (*p*=0.0059 for peak frequency and *p*=0.0033 for peak concentration). Peak frequency and peak concentration were not significantly associated with rush hour or the number of lanes.

Table 4. Results of the univariate analysis for $PM_{2.5}$ peak frequency and peak concentrations at bus stops

Variable	Peak frequency (# peak/hr)	Peak concentration ($\mu g/m^3$)
	Mean ± SD	GM (GSD)
Season		
Spring	17.1 ± 18.8*	90.7 (1.4)*
Autumn	13.0 ± 19.8	83.3 (1.6)
Bus stop location		
Centerline	18.2 ± 22.8*	87.8 (1.4)
Roadside	13.0 ± 16.6	87.4 (1.6)
Time		
Rush hour	13.8 ± 13.6	89.2 (1.5)
Non-rush hour	15.4 ± 21.2	87.0 (1.5)
Smoking [a]		
Smoking period	18.5 ± 29.4*	110.6 (2.0)*
Non-smoking period	13.5 ± 12.9	86.1 (1.4)
Number of buses servicing a route		
1-10	11.9 ± 13.7*	84.5 (1.4)*
11-21	17.7 ± 22.9	89.6 (1.5)
Lanes		
<4	12.3 ± 17.1	84.6 (1.5)
4	15.6 ± 17.4	89.1 (1.5)
>4	16.6 ± 23.4	89.1 (1.4)

*: Statistically significant by Student's t-test ($p<0.05$)

[a]: A Smoking period was defined as when there were smokers at a bus stop and a non-smoking period was defined as when there were no smokers at a bus stop.

Using the significant variables identified in the univariate analysis, a multiple regression analysis of peak frequency was conducted. The significant variables were season, bus stop location, occurrence of smoking, and number of buses servicing a route. Table 5 presents the results of the multiple regression analysis. Peak frequency varied significantly with season, bus stop location, occurrence of smoking, and number of buses servicing a route. The peak frequency in spring was significantly higher than in autumn (p=0.0382). The $PM_{2.5}$ peak frequency at centerline bus stops was significantly higher than at roadside bus stops (p=0.0061). The Peak frequency at bus stops where smoking occurred was significantly higher than that at bus stops without any smokers (p=0.0022). The peak frequency was significantly higher where more buses were servicing the routes (p=0.0399).

Table 5. Multiple regression analysis by a general linear model for $PM_{2.5}$ peak frequency

Variable	β	SE	95% CI	*p*-value
Intercept	29.57	3.33		<.0001
Season				
Spring (reference)				
Autumn	-4.67	2.24	(-9.08, -0.26)	0.0382
Bus stop location				
Centerline (reference)				
Roadside	-6.95	2.51	(-11.90, -2.00)	0.0061
Smoking [a]				
Smoking period (reference)				
Non-smoking period	-8.09	2.62	(-13.26, -2.93)	0.0022
Number of bus servicing a routes				
1–10 (reference)				
11–21	4.75	2.30	(0.22, 9.27)	0.0399

β: Regression coefficient

SE: Standard error

[a]: A Smoking period was defined as when there were smokers at a bus stop and a non-smoking period was defined as when there were no smokers at a bus stop.

Using the significant variables identified in the univariate analysis, a multiple regression analysis for ln-transformed peak concentration was conducted. The significant variables were season, occurrence of smoking, and number of buses servicing a route. Table 6 presents the results of the multiple regression analysis. Peak concentration varied significantly by season, occurrence of smoking, and number of buses servicing a route. The peak concentrations in spring were higher than in autumn (p<0.0001). Peak concentrations at bus stops where smoking occurred were significantly higher than at bus stops with no smokers (p<0.0001). The $PM_{2.5}$ peak concentration was significantly higher where more buses were servicing a route (p=0.0080).

Table 6. Multiple regression analysis by a general linear model for ln-transformed $PM_{2.5}$ peak concentrations

Variable	β	SE	95% CI	*p*-value
Intercept	4.77	0.04		<.0001
Season				
Spring (reference)				
Autumn	-0.09	0.02	(-0.13, -0.05)	<.0001
Smoking [a]				
Smoking period (reference)				
Non-smoking period	-0.25	0.04	(-0.33, -0.18)	<.0001
Number of buses servicing a route				
1–10 (reference)				
11–21	0.06	0.02	(0.01, 0.10)	0.0080

β: Regression coefficient

SE: Standard error

[a]: A Smoking period was defined as when there were smokers at a bus stop and a non-smoking period was defined as when there were no smokers at a bus stop.

3.4 Short-term exposure to $PM_{2.5}$ due to smoking at bus stops

The status of smokers at bus stops was categorized as either standing or walking-through. Figures 2 and 3 show the distributions of peak frequency and peak concentration by smoker status, respectively. Peak frequency did not vary significantly by smoker status (p=0.3698). The peak frequency was 17.1 ± 32.3 peak/hr with smokers standing at the bus stop and 16.6 ± 23.4 peak/hr with smokers walking through the bus stop. However, the peak concentration with standing smokers was significantly higher than with walking-though smokers (p<0.0001). The geometric mean of peak concentrations were 479.9 μg/m^3 (GSD=2.7) with standing smokers and 104.6 μg/m^3 (GSD=1.7) with walking-through smokers.

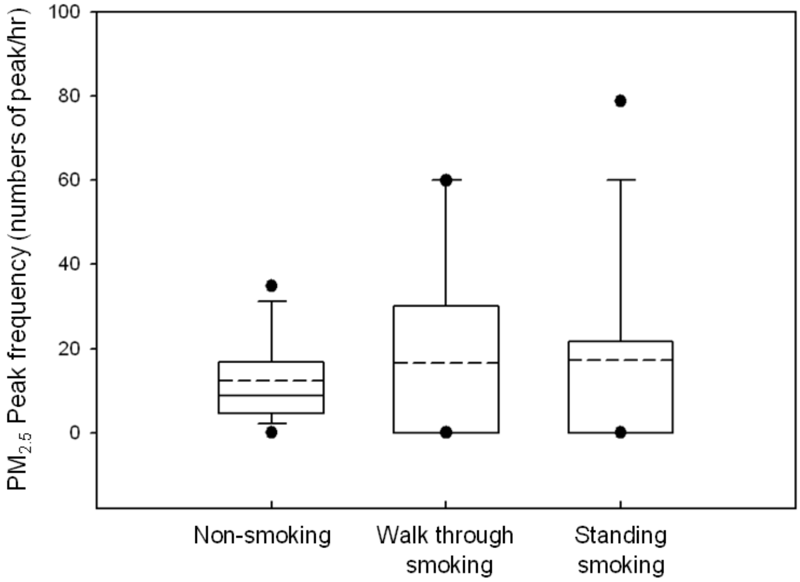

Figure 2. Distribution of peak frequency by smoker status.

Note. Boxes show the median as a center bar, the 25th and 75th percentiles as a box, the 10th and 90th percentile values as the whiskers, and the mean as a dashed line. The upper and lower symbols are 95th and 5th percentile values, respectively.

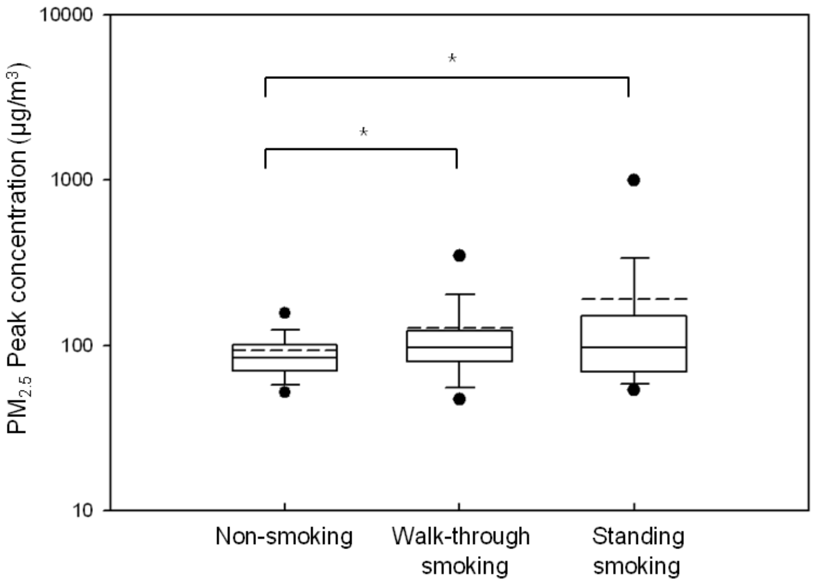

Figure 3. Distribution of peak concentration by smoker status.

Note. * *p*<0.05 is considered statistically significant for Student's t-test. Boxes show the median as a center bar, the 25th and 75th percentiles as a box, the 10th and 90th percentile values as the whiskers, and the mean as a dashed line. The upper and lower symbols are 95th and 5th percentile values, respectively.

The peak frequency and peak concentration with distance from the monitor are shown in Figures 4 and 5, respectively. Peak frequency did not vary significantly when the distance of the smoker from the monitor was increased (p=0.2104), although peak frequency tended to decrease with increasing distance from the monitor. When a smoker was less than 1 m from the monitor, the peak frequency was 27.5 ± 37.4 peak/hr. When a smoker was standing between 1 and 5 m from the monitor, the peak frequency was 19.7 ± 36.0 peak/hr. Peak frequency was 9.1 ± 21.8 peak/hr when a smoker was standing between 5 and 10 m from the monitor. Peak concentrations significantly decreased with increasing distance from a smoker (p=0.0053). The geometric mean of peak concentration was 213.5 μg/m^3 (GSD=3.4) when a smoker was less than 1 m from the monitor, 100.6 μg/m^3 (GSD=1.6) when a smoker was within the range of 1 to 5 m from the monitor, and 84.0 μg/m^3 (GSD=1.5) when a smoker was standing between 5 and 10 m from the monitor.

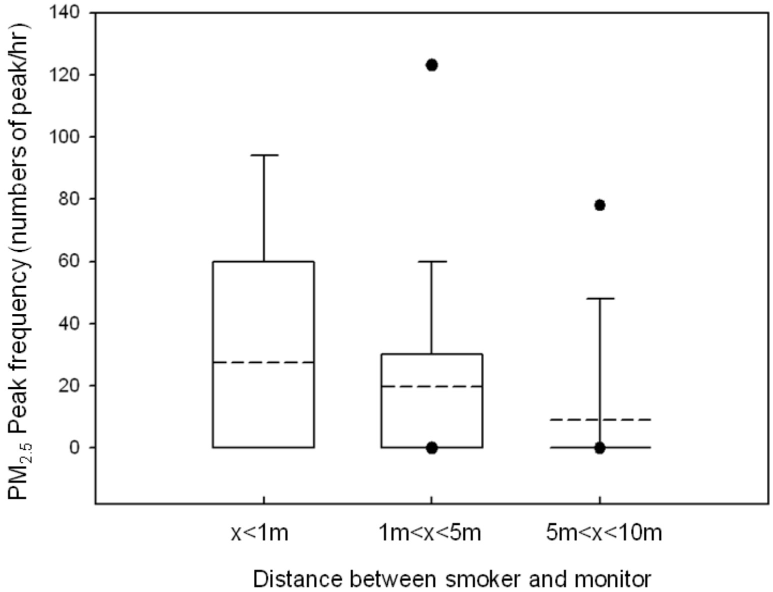

Figure 4. Distribution of peak frequency by distance.

Note. Boxes show the median as a center bar, the 25th and 75th percentiles as a box, the 10th and 90th percentile values as the whiskers, and the mean as a dashed line. The upper and lower symbols are 95th and 5th percentile values, respectively.

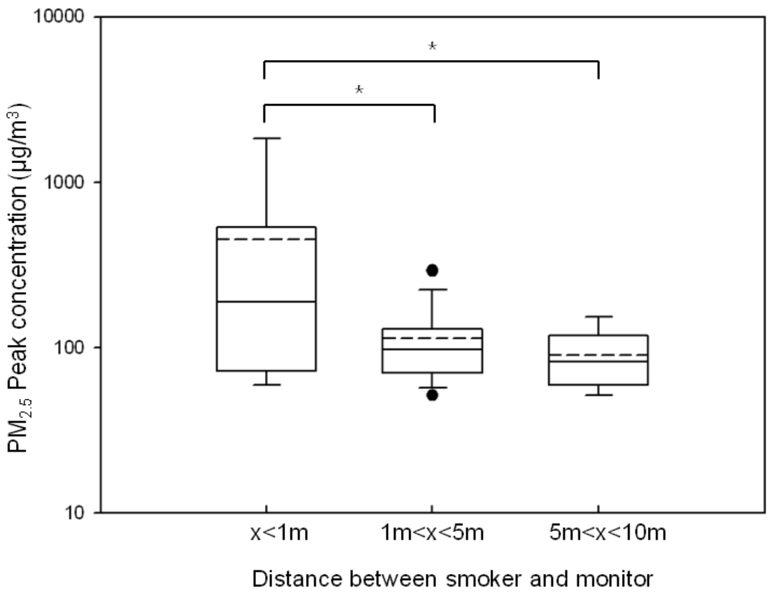

Figure 5. Distribution of peak concentration by distance.

Note. * p<0.05 is considered statistically significant for Student's t-test. Boxes show the median as a center bar, the 25th and 75th percentiles as a box, the 10th and 90th percentile values as the whiskers, and the mean as a dashed line. The upper and lower symbols are 95th and 5th percentile values, respectively.

IV. Discussion

The occurrence of smoking at bus stops was observed before and after the implementation of an outdoor smoke-free policy. Seoul metropolitan city council has initiated an outdoor smoke-free policy only for centerline bus stops. Smoking at centerline bus stops was found to have decreased slightly following the implementation of the policy, but a few smokers were still observed during this study. The occurrence of smoking at roadside bus stops was significantly higher than at centerline bus stops as this study included both smokers who were waiting at the bus stop and passing through the bus stop. The smoke-free policy should be applied to both roadside and centerline bus stops to better control of OTS exposure at bus stops.

$PM_{2.5}$ concentrations at 100 bus stops were measured before and after the implementation of the outdoor smoke-free policy. Although the smoke-free policy commenced on December 1, 2011, fines were not imposed until March 1, 2012. During this introductory period, the impact of the outdoor smoke-free policy on $PM_{2.5}$ concentrations at bus stops could not be fully determined. Thus, $PM_{2.5}$ concentrations measured in autumn 2011 and spring 2012 were combined to determine the significant variables for statistical analysis.

$PM_{2.5}$ levels at bus stops often exceeded the 24-hour US National Ambient Air Quality Standards of 35 $\mu g/m^3$ for $PM_{2.5}$. The average $PM_{2.5}$ concentrations for all 100 bus stops were 20.0 ± 11.8 $\mu g/m^3$ in autumn 2011 and 31.9 ± 14.9 $\mu g/m^3$ in spring 2012. Although the average $PM_{2.5}$

concentrations were less than 35 μg/m^3, 29% of the $PM_{2.5}$ measurements at the bus stops were higher than 35 μg/m^3. In spring, 48% of bus stops had $PM_{2.5}$ concentrations higher than 35 μg/m^3, whereas only 9% of bus stops had $PM_{2.5}$ concentrations higher than 35 μg/m^3 in autumn.

The average $PM_{2.5}$ concentration at bus stops was significantly associated with season. Although the average $PM_{2.5}$ concentration at bus stops was significantly higher after the implementation of the smoke-free policy, the difference might not be an effect of the policy. In Korea, PM levels in spring are usually higher than in autumn. Although ambient monitoring stations in Seoul measured PM_{10} concentrations, ambient $PM_{2.5}$ data was not available. Daily ambient PM_{10} measurements in Seoul indicated that the average PM_{10} concentration in autumn 2011 was 38% lower than in spring 2012. Although $PM_{2.5}$ levels were not measured, high correlations between $PM_{2.5}$ and PM_{10} have been widely reported. In Seoul, a high correlation of 0.89 between ambient $PM_{2.5}$ and PM_{10} mass concentrations was reported in a previous study (Kang *et al.*, 2004). Particulate matter measured at a roadside site with a heavy traffic volume in Hong Kong showed a correlation between $PM_{2.5}$ and PM_{10} of 0.78 for annual data (Chan *et al.*, 2001). Strong correlations were also reported between $PM_{2.5}$ and PM_{10} at seven cities in Switzerland with correlation coefficients of 0.85–0.95 (Gehrig *et al.*, 2003).

In addition to season, bus stop location was identified as a significant variable in the multiple regression analysis of 30-minute integrated $PM_{2.5}$ concentrations at bus stops. $PM_{2.5}$ concentrations at the centerline bus stops were 19% higher than those at roadside bus stops. Centerline bus stops are located in the middle of main streets with heavy traffic volumes, and vehicles run in both directions alongside the bus stops. A roadside bus stop is located on the side of a street and vehicles run only along one side of the bus stop. Therefore, exposures at centerline bus stops are likely to be more influenced by vehicle exhaust. In London, UK, a relationship between particulate matter in an urban area and traffic density was reported (Charron *et al.*, 2005). Outdoor $PM_{2.5}$ concentrations were also significantly increased when truck traffic volumes increased in the Netherlands (Janssen *et al.*, 2001).

The occurrence of smoking was not significantly associated with 30-minute integrated $PM_{2.5}$ concentrations. Smoking occurred only for short periods like 3-5 minutes during the 30-minute measurements. Unlike indoor or outdoor settings with limited air movement, outdoor $PM_{2.5}$ concentrations can change instantly because of wind. Ambient fine particle air pollution can be affected by wind speed or wind direction (Repace, 2000), and thus the average $PM_{2.5}$ concentration might not be the best way to determine OTS levels. Therefore, 'peak analysis' was used to account for the temporal fluctuations of outdoor $PM_{2.5}$ when determining OTS exposure.

Peak analysis was used to identify the occurrence of smoking outdoors. Peak frequency and peak concentration were significantly higher when smoking occurred. When other variables were included in a multiple regression analysis, peak frequency and peak concentration were significantly higher when smokers were present than when no smokers were present. The results demonstrated that peak $PM_{2.5}$ could be used to determine OTS exposure. Peak 30-second OTS concentrations were 4.2 times higher than the mean exposure level measured in the outdoor dining areas of restaurants and cafés (Cameron *et al.*, 2010). In another study reporting on OTS exposure, “microplumes” were defined as thin concentrated smoke streams (Klepeis *et al.*, 2007).

Peak analysis demonstrated the impact of smoker status on OTS. Peak frequency and peak concentration when a smoker standing at a bus stop were higher than when a smoker was walking through a bus stop. Although the peak concentration varied significantly with smoker status, differences in peak frequency were not statistically significant. The exposure time is likely to be longer when a smoker is standing at a bus stop than when they are walking through. This suggests that there is a higher chance of exposure to extremely high levels of $PM_{2.5}$ when a smoker is standing at the bus stop.

When a smoker was standing at a bus stop, both peak frequency and peak concentration decreased with increasing distance between the smoker and monitor. Peak concentrations within 1 m of the smoker were 2.1 and 2.5 times higher than those within radiuses 1 to 5 m and 5 to 10 m, respectively. The outdoor proximity effect, i.e., the average levels from a point source, was inversely proportional to distance (Klepeis *et al.*, 2009). PM concentrations from OTS were quite high within 0.5 m from a burning cigarette and decreased by more than half when the distance increased to 2 m (Klepeis *et al.*, 2007).

This study has several limitations. $PM_{2.5}$ is not a unique tracer of OTS because there are many other outdoor PM sources. However, respirable particulate matter concentration is a tracer that might be related to actual exposure to environmental tobacco smoke, as well as nicotine, and is easy to measure using continuous monitors (Eatough *et al.*, 1989). The Sidepak measurement was adjusted by a correction factor of 0.295. The conversion factor was suitable for SHS, although the correction factor for a light scattering aerosol monitor might vary under ambient conditions and with different types of particles (Jenkins *et al.*, 2004; Jiang *et al.*, 2011). Measurements using a light scattering aerosol monitor were 2.6 to 3.1 times higher than those using a gravimetric method in a study of the non-smoking and smoking sections of hospitals in Louisville, KY (Jenkins *et al.*, 2004). Although the use of the 0.295 correction factor might cause error, such variation is not likely to be significant. Because smoking and smoker behavior were not controlled, it was not possible to consider a range of different smoking conditions. Location-specific meteorological information was not measured because it may have produced a behavioral change in smokers. For the case of a smoker standing at a bus stop, the relationship between the number of smokers and $PM_{2.5}$ concentrations was not determined. During the field measurements, only one smoker was observed at 88% of the bus stops. Some previous OTS studies have indicated that $PM_{2.5}$ concentrations significantly increase as the number of smokers increases (Brennan *et al.*, 2010; St.Helen *et al.*, 2011; Stafford *et al.*, 2010).

V. Conclusion

This study found non-compliance with the outdoor smoke-free policy at bus stops in Seoul. More people smoked at roadside bus stops where the policy was not applied. The policy should be applied to both centerline and roadside bus stops to reduce OTS exposure at the bus stops. Compliance with the outdoor smoke-free policy is critical to achieving clean and comfortable air quality.

Season and bus stop location were associated with outdoor 30-minute $PM_{2.5}$ concentrations. While smoking at bus stops was not associated with 30-minute $PM_{2.5}$ levels, a novel analytical method of 'peak analysis' was able to determine OTS exposure. Peak frequency and peak concentration were significantly associated with smoking occurrence. Peak concentration varied significantly with smoker status and the distance from the smoker to the monitor.

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국문초록

Effects of Outdoor Smoke-Free Policy at Bus Stops on Outdoor Tobacco Smoke Exposure in Seoul

서울시 실외 금연정책 실시와 버스정류장에서의 간접흡연

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서울특별시는 2012 년 3 월, 서울시 소재의 중앙차로 버스정류장을 금연구역으로 지정하고, 실외 금연정책을 실시하였다. 실내 금연정책 시행 여부에 따른 간접흡연 노출에 대한 연구는 많이 이루어졌지만, 실외 금연정책 시행으로 인한 간접흡연 노출 실측 연구는 간접흡연에 대한 건강 위험성이 보고됨에도 불구하고 부족한 실정이다. 따라서 본 연구의 목적은 서울 시민들의 버스정류장에서의 실외 금연정책 이행여부를 조사하고, 버스정류장에서의 미세먼지 농도 수준에 영향을 미치는 인자 및 간접흡연에 따른 미세먼지 노출 수준을 파악하고자 한다.

본 연구는 서울시 소재의 버스정류장 100 개소에서 실시하였으며, 버스정류장 형태에 따라 중앙차로 버스정류장, 차로변 버스정류장 각 50 개소를 선정하였다. 측정은 같은 장소에서 서울특별시 버스정류장 금연정책 실시 전인 2011 년 11 월과 금연정책 실시 이후인 2012 년 3 월, 총 2 회 실시하였다. 각 버스정류장에서 광산란 측정기를 이용하여 미세먼지($PM_{2.5}$) 농도를 1 초 간격으로 30 분 동안 측정하였다. 실외에서 흡연으로 발생한 유해물질은 바람 등의 물리환경적 요인에 의해 순간적으로 농도가 변할 수 있기 때문에, 순간 고농도인 'peak' 를 정의하고 이를 활용한 분석을 실시하였다.

서울특별시 버스정류장 금연정책 실시 전, 총 100 개 버스 정류장 중 46 개소, 금연정책 실시 후에는 37 개소 정류장에서 흡연이 관찰되었다. 금연구역으로 지정된 중앙차로 버스정류장의 경우 흡연율이 75% 감소하였지만, 차로변 버스정류장은 금연정책 실시 전, 후의 큰 차이가 없었다.

Peak 를 이용한 분석 결과, $PM_{2.5}$ peak frequency (단위 시간 당 peak 수)는 계절, 버스정류장 위치, 흡연 여부, 버스 노선 수에 따라 통계적으로 유의한 차이가 있었다. 또한 버스정류장에서의 $PM_{2.5}$ peak 농도 수준은 계절, 흡연 여부, 버스 노선 수에 따라 통계적으로 유의한 차이가 있었다. 흡연 발생 시, 흡연자가 버스정류장에 정지한 상태일 경우 보행상태의 흡연자보다 $PM_{2.5}$

peak 농도 수준이 통계적으로 유의하게 높았다. 이 때 흡연자와의 거리가 가까울수록 $PM_{2.5}$ peak 농도 수준이 유의하게 높았고, $PM_{2.5}$ peak frequency 의 경우 흡연자와의 거리가 증가함에 따라 감소하는 경향을 보였지만 통계적으로 유의하지는 않았다.

본 연구를 통해 서울 시민들의 버스정류장 금연정책 이행여부를 파악할 수 있었다. 금연구역인 중앙차로 버스정류장에 비해 금연구역으로 지정되지 않은 차로변 버스정류장에서 더욱 많은 흡연자가 관찰되었다. 보다 효과적인 버스정류장 금연정책을 위해서는 서울시 소재의 전체 버스정류장을 금연구역으로 지정하는 것이 바람직할 것이다. 그리고 실외 간접흡연 노출수준을 파악하는데 peak 의 개념을 이용한 분석방법이 유용하게 활용될 수 있을 것이다.

주요어 : 금연정책, 실외, 미세먼지($PM_{2.5}$), 버스정류장, Peak

학 번 : 2011-22059