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Impact of Partial and Comprehensive Smoke-Free Regulations on Indoor Air Quality in Bars

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Abstract: In Korea, smoke-free regulations have been gradually implemented in bars based on venue size. Smoking bans were implemented in 2013 for bars ≥ 150 m², in 2014 for bars ≥ 100 m², and in 2015 for bars of all sizes. The purpose of this study was to determine indoor fine particle (PM_{2.5}) concentrations in bars before and after implementation of the smoke-free policies based on venue size. Indoor PM_{2.5} concentrations were measured with real-time aerosol monitors at four time points: (1) pre-regulation ($n = 75$); (2) after implementing the ban in bars ≥ 150 m² ($n = 75$); (3) after implementing the ban in bars ≥ 100 m² ($n = 107$); and (4) when all bars were smoke-free ($n = 79$). Our results showed that the geometric mean of the indoor PM_{2.5} concentrations of all bars decreased from 98.4 $\mu\text{g}/\text{m}^3$ pre-regulation to 79.5, 42.9, and 26.6 $\mu\text{g}/\text{m}^3$ after the ban on smoking in bars ≥ 150 m², ≥ 100 m², and all bars, respectively. Indoor PM_{2.5} concentrations in bars of each size decreased only after the corresponding regulations were implemented. Although smoking was not observed in Seoul bars after smoking was banned in all bars, smoking was observed in 4 of 21 bars in Changwon. Our study concludes that the greatest decrease in PM_{2.5} concentrations in bars was observed after the regulation covering all bars was implemented. However, despite the comprehensive ban, smoking was observed in bars in Changwon. Strict compliance with the regulations is needed to improve indoor air quality further.

Keywords: indoor air quality; PM_{2.5}; pub; environmental tobacco smoke; smoke-free regulation

1. Introduction

Environmental tobacco smoke (ETS), also known as passive smoking, is the combination of secondhand smoke and thirdhand smoke [1]. ETS contains a complex mixture of 7000 chemicals that includes 69 known carcinogens [2]. Exposure to ETS is associated with cardiovascular disease, asthma, other respiratory symptoms, and lung cancer [3–6]. There is no risk-free level of ETS exposure and breathing small amounts of ETS can cause adverse health effects [6]. In 2004, 603,000 premature deaths were attributed to ETS exposure, equivalent to 1.0% of worldwide mortality, based on data from 192 countries [7]. Moreover, in 2006, 33,951 American adults died from ischemic heart disease and 7333 died from lung cancer based on estimations of ETS-attributable deaths [8]. Particulate matter with aerodynamic diameters <2.5 μm (PM_{2.5}) is often used as proxy measures of tobacco smoke pollution

in indoor environments [9–13]. PM_{2.5} exposure has been associated with increased mortality [14], coronary heart disease [15], and lung cancer [16].

Many countries have implemented smoke-free regulations to reduce ETS exposure in indoor public spaces and workplaces. For example, indoor PM_{2.5} concentrations in 42 Irish pubs decreased by 83% one year after implementing comprehensive smoke-free legislation [9]. In Michigan, USA, the indoor PM_{2.5} concentrations of 78 restaurants decreased by 91% after implementing a smoking ban [17].

In 2012, the Korean government amended Article 9 of the National Health Promotion Act to legislate smoke-free regulations in public indoor spaces, including hospitality venues. However, many commercial hospitality venues, such as bars, were granted gradual introduction of the smoking ban based on their net indoor area. The regulations were implemented on 1 July 2013 for bars ≥ 150 m², 1 January 2014 for bars ≥ 100 m², and 1 January 2015 for bars of all sizes.

The venue size-based regulations resulted in smaller reductions of indoor PM_{2.5} concentrations in hospitality venues compared to the comprehensive smoke-free regulation. In 2013, indoor PM_{2.5} concentrations were measured before and after the ban in Seoul bars ≥ 150 m² [18]. While indoor PM_{2.5} concentrations in bars < 150 m² did not change, the geometric mean (GM) of indoor PM_{2.5} concentrations in the bars ≥ 150 m² ($n = 34$) decreased by 41%, from 93.2 to 55.3 $\mu\text{g}/\text{m}^3$, 1 month after implementation of the ban. After the smoke-free regulation was applied to bars ≥ 100 m² in 2014, the arithmetic mean of the difference between indoor and outdoor PM_{2.5} concentrations in bars 100–149 m² ($n = 20$) decreased by 72%, from 115.1 $\mu\text{g}/\text{m}^3$ pre-regulation to 32.4 $\mu\text{g}/\text{m}^3$ [19]. However, indoor PM_{2.5} concentrations in bars < 100 m² did not change. Although studies from other countries reported that indoor PM_{2.5} concentrations in hospitality venues decreased by 80%–90% after enacting comprehensive smoke-free regulations [9,17,20], the reduction in indoor PM_{2.5} concentrations in Korean bars regulated by venue size was relatively low.

Gradual implementation of the smoking ban in Korean bars based on venue size has provided an opportunity to evaluate indoor PM_{2.5} concentrations in bars over time. In our first study, we evaluated indoor air quality in bars ≥ 150 and < 150 m² pre- and post-regulation of bars ≥ 150 m² in 2013 [18]. Then, we compared indoor air quality in bars 100–149 and < 100 m² when the regulation was applied to bars ≥ 100 m² in 2014 [19]. Since our previous studies only partially evaluated the venue-size-based smoke-free regulation in bars, a complete evaluation of the gradual implementation of the smoke-free regulation is necessary. Therefore, we conducted this study to determine indoor PM_{2.5} concentrations in bars of different sizes before and after the regulation was applied to bars ≥ 150 m² and ≥ 100 m², and to all bars in Seoul and Changwon, Korea.

2. Materials and Methods

2.1. Study Population

We measured indoor PM_{2.5} concentrations in bars at four time points in Seoul (pre- and post-regulation of bars ≥ 150 m², ≥ 100 m², and in all bars) and at two time points in Changwon (post-regulation of bars ≥ 100 m² and post-regulation of all bars). In 2012, Seoul, the capital of Korea, had a population of ~10.2 million people in an area of 605.3 km². Changwon, a provincial city, has a population of ~1.1 million people in an area of 743.8 km².

Bars were selected using convenience sampling based on the accessibility of the bars, and non-proportional quota samples based on their size (≥ 150 , 100–149, and < 100 m²). Indoor PM_{2.5} concentrations in bars of different sizes were measured before the regulation (April–June 2013) and after the regulation of bars ≥ 150 m² (August–September 2013) (Seoul, $n = 75$) [18], bars ≥ 100 m² (July–December 2014) (Seoul, $n = 76$; Changwon, $n = 33$) [19], and all bars (July–October 2015) (Seoul, $n = 58$; Changwon, $n = 21$). Data from two Changwon bars in 2014 were excluded due to misclassification of bar size. Overall, in total 336 samples of indoor PM_{2.5} concentrations in 148 bars were collected.

2.2. Sample Collection

PM_{2.5} concentrations were measured using a portable real-time aerosol monitor (AM510; TSI Inc., Shoreview, MN, USA). The monitor was equipped with a PM_{2.5} impactor to remove particles >2.5 μm and the logging interval was set to 1 min with flow rates of 1.7 L/min. The monitor was zero-calibrated with a high efficiency particulate air filter following standard operating procedures each day before beginning the PM_{2.5} measurements. Because the monitor used light-scattering methods to obtain the particle concentrations, the measurements were converted using a factor of 0.295, obtained from collocated measurements using the monitor against gravimetric methods [21].

One or two field technicians visited bars between 18:00 and 24:00 h on a weekday to measure the indoor PM_{2.5} concentrations. The technicians concealed the monitor in a small bag and continuously collected PM_{2.5} samples before and after entry into the bars for 5 min ($n = 10$), and during the visit for 30 min ($n = 30$). The samples from each indoor and outdoor location were averaged to obtain average indoor and outdoor PM_{2.5} concentrations. The monitor was placed on a table or seat in each bar as far as possible from air-conditioning and heating equipment, doors, windows, and other direct PM_{2.5} sources. The field technician recorded the characteristics of the bars including net indoor area and volume, and counted the number of vents, burning cigarettes, and patrons. The number of patrons was counted every 5 min and averaged to provide a 30-min average number of patrons. When field technicians re-visited the same bars, indoor PM_{2.5} concentrations were measured at a time similar to that of the initial visit.

2.3. Statistical Analysis

The Kolmogorov-Smirnov test was verified to test the normality of indoor and outdoor PM_{2.5} concentrations. Because indoor and outdoor PM_{2.5} concentrations were not normally distributed, they were log-transformed for statistical analysis. The indoor and outdoor PM_{2.5} concentrations were described as the GM and geometric standard deviation (GSD). Wilcoxon's signed rank test was used to compare differences between indoor and outdoor PM_{2.5} concentrations because the differences between the indoor and outdoor PM_{2.5} concentrations were not normally distributed. An analysis of variance (ANOVA) test was used to compare pre-regulation indoor PM_{2.5} concentrations among bars ≥ 150 , 100–149, and < 100 m². Student's *t*-test was used to compare: pre-regulation indoor PM_{2.5} concentrations in all bars and bars ≥ 150 , 100–149, and < 100 m² with those after regulation of bars ≥ 150 m²; indoor PM_{2.5} concentrations in all bars in Seoul with those of Changwon after regulation of bars ≥ 100 m²; indoor PM_{2.5} concentrations in bars 100–149 m² after regulation of bars ≥ 100 m² with those after regulation of bars ≥ 150 m² and those before any regulation; indoor PM_{2.5} concentrations in all bars in Seoul with those of Changwon after regulation of all bars; indoor PM_{2.5} concentrations in bars < 100 m² after regulation of all bars with those after regulation of bars ≥ 100 m² and ≥ 150 m² and those before any regulation; indoor PM_{2.5} concentrations in bars < 100 m² after regulation of bars ≥ 100 m² with those after regulation of bars ≥ 150 m². The Wilcoxon rank-sum test was used to compare indoor PM_{2.5} concentrations in bars in which smokers were observed with those in which no smokers were observed after the regulation in all bars because the number of samples in bars in which smoker were observed ($n = 4$) was small for parametric analysis. All statistical analyses were conducted using SAS software (ver. 9.3; SAS Institute Inc., Cary, NC, USA), those with *p*-values of < 0.05 were considered to be significant. SigmaPlot software (ver. 10; Systat Software, Inc., Chicago, IL, USA) was used to draw the graphs.

3. Results

3.1. Indoor PM_{2.5} Concentrations of Bars Pre-Regulation

Table 1 shows the indoor PM_{2.5} concentrations in bars and the number of bars in which smokers were observed before and after regulation of bars ≥ 150 m², ≥ 100 m², and all bars in Seoul and Changwon. The GM of indoor and outdoor PM_{2.5} concentrations of the 336 sample periods from

148 bars under different regulations were $53.0 \mu\text{g}/\text{m}^3$ (GSD = 2.9) and $23.3 \mu\text{g}/\text{m}^3$ (GSD = 2.1), respectively. Indoor levels were significantly higher than outdoor levels ($p < 0.001$). The GM of indoor $\text{PM}_{2.5}$ concentrations of bars pre-regulation was $98.4 \mu\text{g}/\text{m}^3$ (GSD = 2.1, $n = 75$) and indoor $\text{PM}_{2.5}$ concentrations did not differ by bar size ($p = 0.447$). Pre-regulation, smoking was observed in 68% of bars $\geq 150 \text{ m}^2$, 96% of bars 100–149 m^2 , and 94% of bars $< 100 \text{ m}^2$.

3.2. Indoor $\text{PM}_{2.5}$ Concentrations in Bars $\geq 150 \text{ m}^2$ after Regulation of Bars $\geq 150 \text{ m}^2$

The GM of indoor $\text{PM}_{2.5}$ concentrations in all bars was $79.5 \mu\text{g}/\text{m}^3$ (GSD = 2.2, $n = 75$) after regulation of bars $\geq 150 \text{ m}^2$. The indoor $\text{PM}_{2.5}$ concentrations in all bars after regulation of bars $\geq 150 \text{ m}^2$ was lower, but not statistically significant ($p = 0.092$), than the pre-regulation concentrations. In bars $\geq 150 \text{ m}^2$, the GM of indoor $\text{PM}_{2.5}$ concentrations were $93.2 \mu\text{g}/\text{m}^3$ (GSD = 2.2, $n = 34$) pre-regulation and $55.3 \mu\text{g}/\text{m}^3$ (GSD = 2.2, $n = 34$) after regulation of bars $\geq 150 \text{ m}^2$ (Figure 1). Indoor levels in bars $\geq 150 \text{ m}^2$ after regulation of bars $\geq 150 \text{ m}^2$ were significantly lower than those pre-regulation ($p = 0.008$), while levels in bars of other sizes did not differ. Although less smoking was observed, it was still observed in 29% of bars $\geq 150 \text{ m}^2$ after the regulation of bars $\geq 150 \text{ m}^2$.

3.3. Indoor $\text{PM}_{2.5}$ Concentrations in Bars 100–149 m^2 after Regulation of Bars $\geq 100 \text{ m}^2$

After the regulation of bars $\geq 100 \text{ m}^2$, the GM of indoor $\text{PM}_{2.5}$ concentrations in all bars were $47.1 \mu\text{g}/\text{m}^3$ (GSD = 2.9, $n = 76$) in Seoul and $34.2 \mu\text{g}/\text{m}^3$ (GSD = 4.2, $n = 31$) in Changwon, which were not significantly different ($p = 0.270$). In Seoul, the indoor $\text{PM}_{2.5}$ concentration in bars 100–149 m^2 was $38.6 \mu\text{g}/\text{m}^3$ (GSD = 2.8, $n = 36$) after the regulation of bars $\geq 100 \text{ m}^2$. Indoor $\text{PM}_{2.5}$ concentrations in bars 100–149 m^2 were significantly lower than those after the regulation of bars $\geq 150 \text{ m}^2$ ($118.9 \mu\text{g}/\text{m}^3$, GSD = 2.1, $n = 24$, $p < 0.001$) and those pre-regulation ($114.9 \mu\text{g}/\text{m}^3$, GSD = 2.1, $n = 24$, $p < 0.001$) (Figure 2). Smoking was observed in 33% of bars 100–149 m^2 in Seoul and in 29% of bars 100–149 m^2 in Changwon after the regulation of bars $\geq 100 \text{ m}^2$.

Table 1. Indoor PM_{2.5} concentrations (µg/m³) in bars and number of bars in which smokers were observed before and after smoke-free regulations were implemented in bars ≥150 m², bars ≥100 m², and in bars of all sizes in Seoul and Changwon.

City	Size (m ²)	Pre-Regulation ^a		After Regulation of Bars ≥150 m ² ^a		After Regulation of Bars ≥100 m ² ^b		After Regulation of All Bars					
		<i>n</i>	Indoor PM _{2.5} Concentration	Bars with Smokers	<i>n</i>	Indoor PM _{2.5} Concentration	Bars with Smokers	<i>n</i>	Indoor PM _{2.5} Concentration	Bars with Smokers			
			GM (GSD)	# (%)		GM (GSD)	# (%)		GM (GSD)	# (%)			
Seoul	≥150	34	93.2 (2.2)	23 (68)	34	55.3 (2.2)	10 (29)	-	-	-	7	23.3 (2.2)	0 (0)
	100–149	24	114.9 (2.1)	23 (96)	24	118.9 (2.1)	16 (67)	36	38.6 (2.8)	12 (33)	11	19.7 (2.4)	0 (0)
	<100	17	88.2 (1.9)	16 (94)	17	93.4 (1.7)	12 (71)	40	56.3 (2.9)	20 (50)	40	26.5 (2.4)	0 (0)
	Subtotal	75	98.4 (2.1)	62 (83)	75	79.5 (2.2)	38 (51)	76	47.1 (2.9)	32(42)	58	24.7 (2.3)	0 (0)
Changwon	≥150	-	-	-	-	-	-	-	-	-	-	-	-
	100–149	-	-	-	-	-	-	14	21.6 (3.0)	4 (29)	4	27.8 (3.6)	2 (50)
	<100	-	-	-	-	-	-	17	50.0 (4.9)	9 (53)	17	33.7 (2.7)	2 (12)
	Subtotal	-	-	-	-	-	-	31	34.2 (4.2)	13 (42)	21	32.5 (2.8)	4 (19)
Total		75	98.4 (2.1)	62 (83)	75	79.5 (2.2)	38 (51)	107	42.9 (3.3)	45 (42)	79	26.6 (2.5)	4 (5)

^a Data published in Kim et al. [18]; ^b Data published in Kim et al. [19]; GM: geometric mean; GSD: geometric standard deviation.

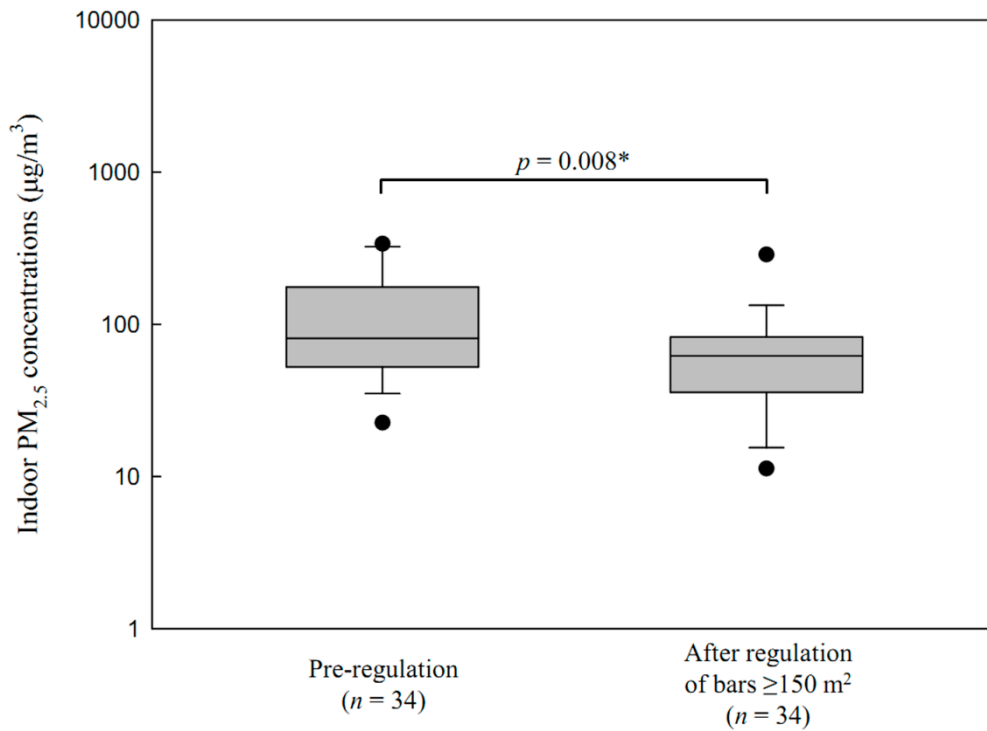


Figure 1. Distribution of indoor PM_{2.5} concentrations in Seoul bars, pre-regulation, ≥150 m², and after the regulation of bars ≥150 m². * Student’s *t*-test.

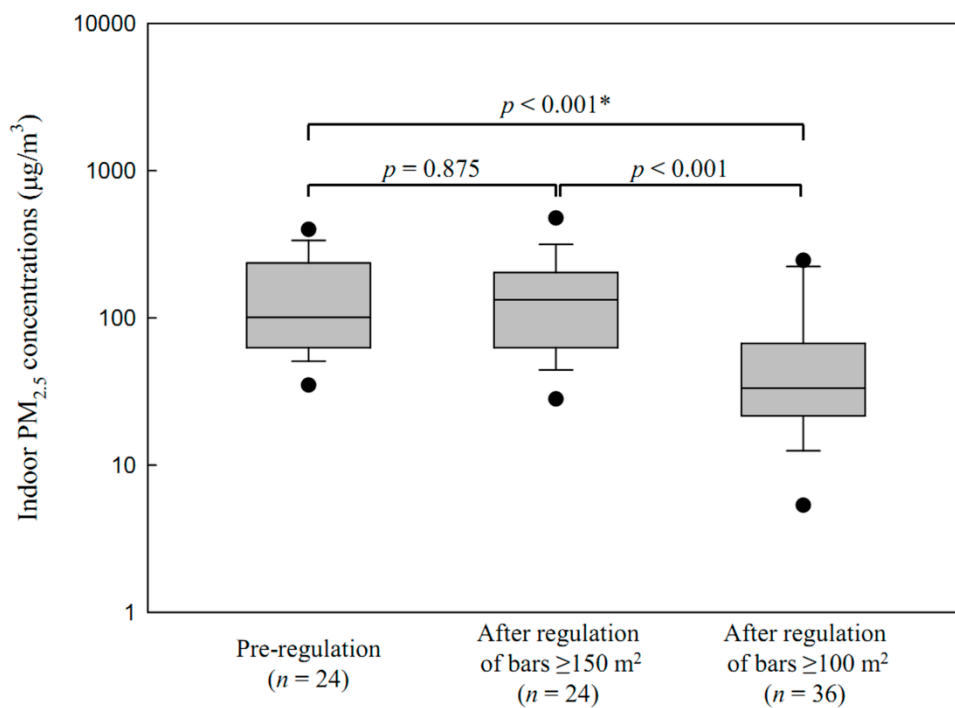


Figure 2. Distribution of indoor PM_{2.5} concentrations in Seoul bars, pre-regulation, 100–149 m², and after the regulation of bars ≥150 m², bars ≥100 m². * Student’s *t*-test.

3.4. Indoor PM_{2.5} Concentrations in Bars <100 m² after Regulation of All Bars

After the smoking ban in all bars, the GM of indoor PM_{2.5} concentrations in bars <100 m² were 24.7 µg/m³ (GSD = 2.3, *n* = 58) in Seoul and 32.5 µg/m³ (GSD = 2.8, *n* = 21) in Changwon; these values were not significantly different (*p* = 0.237).

In Seoul, the GM of indoor PM_{2.5} concentrations in bars <100 m² was 26.5 µg/m³ (GSD = 2.4, *n* = 40) after regulating all bars; these values were significantly lower than those after regulation of bars ≥100 m² (56.3 µg/m³, GSD = 2.9, *n* = 40, *p* < 0.001), regulation of bars ≥150 m² (93.4 µg/m³, GSD = 1.7, *n* = 17, *p* < 0.001), and pre-regulation (88.2 µg/m³, GSD = 1.9, *n* = 17, *p* < 0.001) (Figure 3). Smoking was not observed in Seoul bars <100 m² after regulating all bars. In Changwon, the GM of indoor PM_{2.5} concentrations in bars <100 m² was 33.7 µg/m³ (GSD = 2.7, *n* = 17) after regulation of all bars. The GM of indoor PM_{2.5} concentrations in bars <100 m² was 50.0 µg/m³ (GSD = 4.9, *n* = 17) after regulation of bars ≥100 m². The levels after the regulation of all bars were lower, but not significantly different (*p* = 0.397), than those after the regulation of bars ≥100 m². Smoking was observed in 19% of bars <100 m² after regulation of all bars.

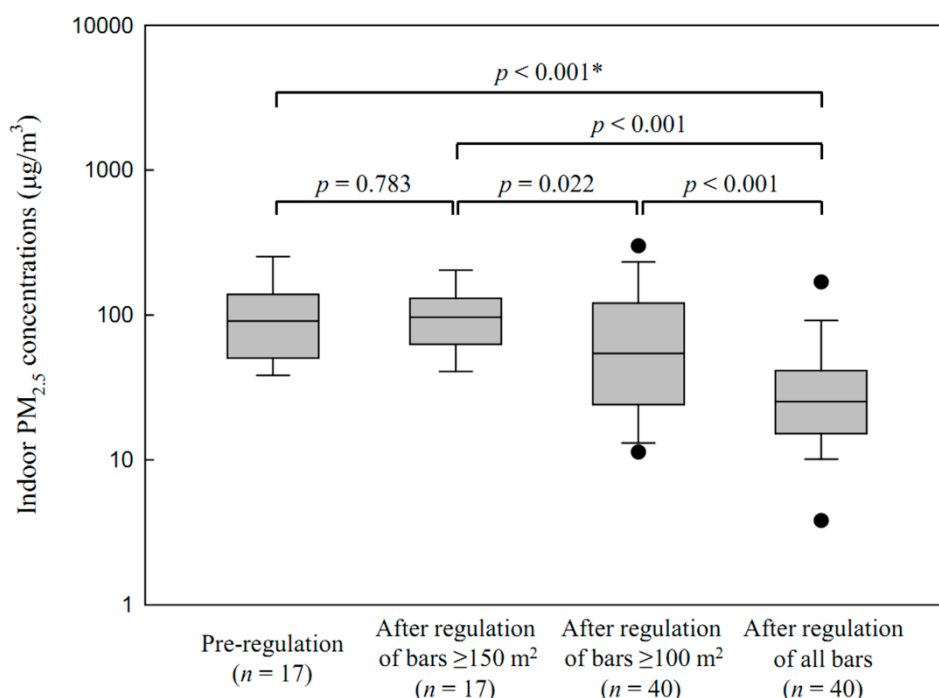


Figure 3. Distribution of indoor PM_{2.5} concentrations in Seoul bars, pre-regulation, <100 m², and after the regulation of bars ≥150 m², bars ≥100 m², and bars of all sizes. * Student's *t*-test.

3.5. Factors Associated with Indoor PM_{2.5} Concentrations after Regulation of All Bars

After regulation of all bars, GM of indoor and outdoor PM_{2.5} concentrations of all bars were 26.6 µg/m³ (GSD = 2.5, *n* = 79) and 14.9 µg/m³ (GSD = 2.1, *n* = 79), respectively. The indoor levels were significantly higher than the outdoor levels (*p* < 0.001). The indoor PM_{2.5} concentrations were only associated with the presence of smoking. Smoking was observed only in Changwon, where the GM of indoor PM_{2.5} concentrations in bars with and without smokers observed were 119.0 µg/m³ (GSD = 2.0, *n* = 4) and 23.9 µg/m³ (GSD = 2.3, *n* = 17), respectively; these values differed significantly (*p* = 0.018; Figure 4). However, indoor PM_{2.5} concentrations in bars in Seoul and Changwon were not associated with indoor volume or number of patrons and vents.

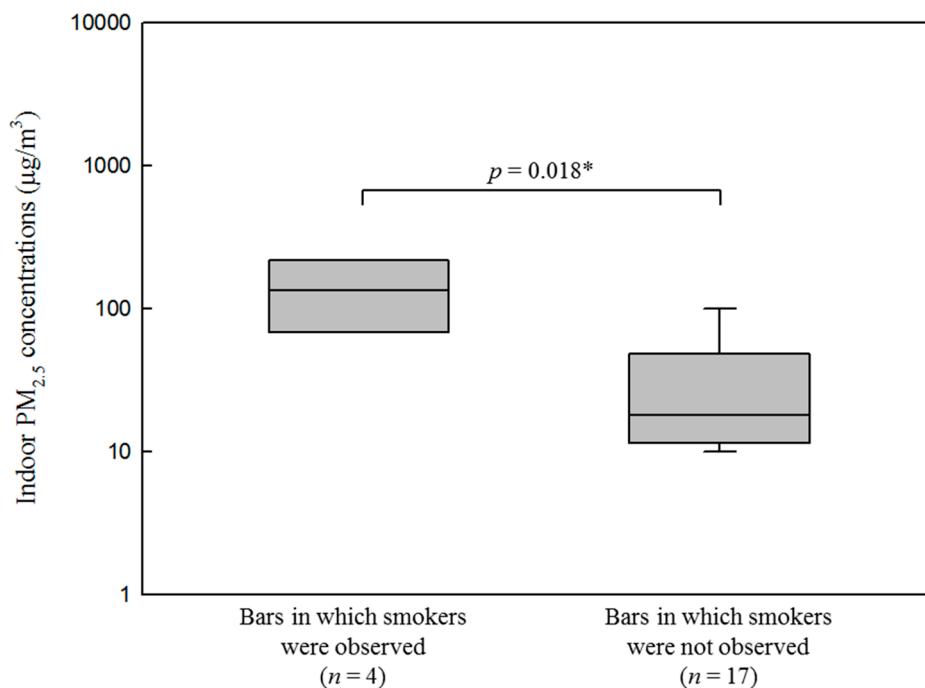


Figure 4. Distribution of indoor PM_{2.5} concentrations of bars in which smokers were and were not observed after the smoke-free regulations were implemented in all bars in Changwon. * Wilcoxon's rank-sum test.

4. Discussion

Implementing smoke-free regulations increasingly over three years resulted in a gradual improvement of indoor air quality in all bars. Before any regulations were implemented, indoor PM_{2.5} concentrations in all bars were 2.8 times higher than the National Ambient Air Quality Standard (NAAQS) for daily PM_{2.5} of 35 µg/m³. The indoor PM_{2.5} levels decreased by 19% after the regulation of bars ≥150 m². When the regulations were implemented in bars ≥100 m², indoor PM_{2.5} concentrations in all bars after the regulation of bars ≥150 m² decreased by 46%. After regulation of all bars, indoor PM_{2.5} concentrations in all bars decreased by 38% compared to levels after the regulation of bars ≥100 m², and PM_{2.5} levels no longer exceeded the NAAQS for daily PM_{2.5}. Furthermore, after regulation of all bars, the overall indoor PM_{2.5} concentrations in all bars decreased by 73%. This result of gradual improvement in indoor air quality with increasingly stringent smoke-free regulations was similar to that of a study carried out in Greece [22]. Indoor PM_{2.5} concentrations in hospitality venues (e.g., bars, cafés, and restaurants) decreased from 268 µg/m³ pre-regulation to 174 µg/m³ after the ban on smoking in venues >70 m² and to 89 µg/m³ after the comprehensive ban.

Indoor air quality in bars only improved after the regulations corresponding to venue size were implemented. In Seoul, indoor PM_{2.5} concentrations in bars ≥150 m² decreased by 41% after its regulation of bars ≥150 m². Moreover, after the regulation of bars ≥100 m², indoor PM_{2.5} concentrations in bars 100–149 m² were 68% and 66% lower than those after regulation of bars ≥150 m² and pre-regulation, respectively. After all bars were regulated, indoor PM_{2.5} concentrations in bars <100 m² were 53%, 72%, and 70% lower than those after regulation of bars ≥100 m², ≥150 m², and pre-regulation, respectively. However, indoor PM_{2.5} concentrations did not change substantially in bars until their corresponding size-based regulations were implemented. In Changwon, indoor PM_{2.5} concentrations in bars <100 m² after regulation of all bars were 33% lower than those after regulation of bars ≥100 m². The slight change after regulation of all bars compared with regulation of bars ≥100 m² may have been because indoor smoking was observed in some bars after the regulation of all bars. The results of this study indicated that implementing regulations in bars based on venue size did not

improve indoor air quality in bars not covered by that regulation. Similar results have been reported in Spain [23]. In January 2006, regulations were passed mandating that Spanish bars and restaurants >100 m² had to be either smoke-free or have a smoking section of no more than 30% of the total venue area; however, this regulation did not include venues ≤100 m². When indoor nicotine concentrations were measured before and ~1 year after the regulations, the median indoor nicotine concentrations in venues that became smoke-free decreased by 96.7%, while indoor nicotine concentrations in venues where smoking was allowed throughout the premises were not significantly changed.

Banning smoking in all bars effectively improved indoor air quality. It is interesting to note that the impact of the regulation on larger bars was greater when the regulation of the bars became comprehensive. This might reflect the fact that when other bars allowed smoking (smaller bars), the larger bars did not fully enforce banning smoking. The possible reason is that the bar owners did not want to lose patrons to smaller bars. When the regulation covered all bars, this might not constitute a problem and enforcement might be fully carried out. A previous study reported that implementing smoking bans in hospitality venues without exemptions resulted in a significant reduction of indoor PM_{2.5} concentrations. The Spanish smoking-free regulation was amended implementing indoor smoking in all hospitality venues since January 2011. The median indoor PM_{2.5} concentrations decreased by 92%, from 233.4 µg/m³ in 2010 to 18.8 µg/m³ in 2011 [24]. In bars across Scotland and England, indoor PM_{2.5} concentrations were measured before and two months after a smoking ban. The median indoor PM_{2.5} concentrations decreased by 91% (from 197 to 15 µg/m³) in Scotland and 93% (from 92 to 11 µg/m³) in England [10]. Median indoor PM_{2.5} concentrations before and 12 months after a ban in Wales decreased by 85% (from 184 to 24 µg/m³). In Kentucky, USA, the average indoor PM_{2.5} concentrations in 62 hospitality venues decreased by 88% (from 161 to 20 µg/m³) after a comprehensive smoking ban [20].

Although the smoking ban was implemented in all bars, indoor smoking was observed in some bars in Changwon, where indoor PM_{2.5} concentrations of bars with smokers were five times higher than those of bars in which smokers were not observed. Strict enforcement of the regulation in bars in such cities is necessary to improve indoor air quality.

After the regulation in all bars, indoor PM_{2.5} concentrations of bars were higher than outdoor PM_{2.5} concentrations. When we compared 75 pairs of indoor and outdoor PM_{2.5} concentrations of bars in which no smokers were observed after the regulation in all bars, the indoor levels (24.5 µg/m³, GSD = 2.4) were significantly higher than outdoor levels (15.4 µg/m³, GSD = 2.1) ($p < 0.001$). Higher levels of indoor PM_{2.5} concentrations than outdoor PM_{2.5} concentrations might be due to human activity and cooking. These activities might be associated with occupancy density. However, no associations between the indoor PM_{2.5} concentrations and number of patrons were found. Further studies can be helpful for improving indoor air quality further.

This study had several limitations: first, because it was conducted during different seasons over three years, there may have been seasonal variations due to different mechanical and natural ventilation conditions. In addition, although we measured PM_{2.5} concentrations in bars following standard operating procedures, there may have been variations by time of day and day of the week. Finally, we did not randomly select bars by size in the two cities. Because of these limitations in the study design, our findings should not be generalized to other cases.

5. Conclusions

Indoor PM_{2.5} concentrations in bars of different sizes were measured before smoking and after the implementation of smoking bans in bars ≥150 m², ≥100 m², and in all bars. The indoor PM_{2.5} concentration of all bars gradually decreased with increasingly stringent regulation. Indoor PM_{2.5} concentrations of bars of specific sizes decreased after the corresponding regulations were implemented and indoor air quality in bars was most improved after regulation of all bars. Although not observed in Seoul, smoking was observed in some bars in Changwon, even after the comprehensive smoking ban. Compliance with strict regulations is needed to further improve indoor air quality.

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Author Contributions: Jeonghoon Kim, Yunhyung Hwang, Kiyoung Lee, and Kwonchul Ha developed the concept and designed the study. Hyunkyung Ban collected and managed the field data. Jeonghoon Kim and Kiyoung Lee were responsible for drafting the manuscripts and the data analysis. All authors read and approved the final manuscripts.

Conflicts of Interest: The authors declare no conflict of interest.

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