Original Investigation

Strength of smoke-free air laws and indoor air quality

Kiyoung Lee, Ellen J. Hahn, Heather E. Robertson, Seongjik Lee, Suzann L. Vogel, & Mark J. Travers

Abstract

Introduction: Smoke-free air laws have been implemented in many Kentucky communities to protect the public from the harmful effects of secondhand smoke exposure. The impact of different strengths of smoke-free air laws on indoor air quality was assessed.

Methods: Indoor air quality in hospitality venues was assessed in seven communities before and after comprehensive smoke-free air laws and in two communities only after partial smoke-free air laws. One community was measured three times: before any smoke-free air law, after the initial partial law, and after the law was strengthened to cover all workplaces and public places with few exemptions. Real-time measurements of particulate matters with 2.5 μm aerodynamic diameter or smaller ($\text{PM}_{2.5}$) were obtained.

Results: When comprehensive smoke-free air laws were implemented, indoor $\text{PM}_{2.5}$ concentrations decreased significantly from 161 to 20 $\mu\text{g}/\text{m}^3$. In one community that implemented a comprehensive smoke-free law after initially passing a partial law, indoor $\text{PM}_{2.5}$ concentrations were 304 $\mu\text{g}/\text{m}^3$ before the law, 338 $\mu\text{g}/\text{m}^3$ after the partial law, and 9 $\mu\text{g}/\text{m}^3$ after the comprehensive law.

Discussion: The study clearly demonstrated that partial smoke-free air laws do not improve indoor air quality. A significant linear trend indicated that $\text{PM}_{2.5}$ levels in the establishments decreased with fewer numbers of burning cigarettes. Only comprehensive smoke-free air laws are effective in reducing indoor air pollution from secondhand tobacco smoke.

Introduction

Cigarette smoking is the single most preventable cause of morbidity and mortality, and secondhand smoke (SHS) is the third

leading preventable cause of death in the United States (U.S. Department of Health and Human Services, 2006). SHS, which consists of a mixture of the smoke given off by the burning end of tobacco products (side stream smoke) and the smoke exhaled by smokers (mainstream smoke), is a major source of indoor air pollution containing a complex mixture of more than 4,000 chemicals, more than 50 of which are known cancer-causing agents (U.S. Department of Health and Human Services, 2006). SHS is also associated with an increased risk for cardiovascular disease, respiratory illness, and lung cancer among both smokers and nonsmokers (U.S. Department of Health and Human Services, 2006).

The most effective measure to reduce exposure to SHS is to remove the source from indoor environments. As of 4 January 2009 in the United States, 16,505 local municipalities are covered by either local or state 100% smoke-free air laws in workplaces and/or restaurants and/or bars (American Nonsmokers Rights Foundation, 2009). It is estimated that approximately 70% of the U.S. population are protected by clean indoor air regulations that cover virtually all indoor work-sites including bars and restaurants. There are 2,982 local ordinances or regulations that restrict smoking to some extent in workplaces across the United States and Washington, DC (American Nonsmokers Rights Foundation, 2009). The extent of protection provided by these laws vary widely from community to community.

As of 1 July 2008, 16 communities in Kentucky had enacted and implemented smoke-free air laws. The most comprehensive ordinances, smoke-free workplace and smoke-free enclosed public place laws, had been implemented in six communities. Four communities had implemented smoke-free public place laws including restaurants, bars, and other businesses open to the public. Six communities had implemented partial smoke-free air laws, protecting workers, and patrons in some but not all public venues.

Kiyoung Lee, Sc.D., *Graduate School of Public Health and Institute of Health and Environment, Seoul National University, Seoul, Korea*

Ellen J. Hahn, D.N.S., *Tobacco Policy Research Program, College of Nursing, University of Kentucky, Lexington, KY*

Heather E. Robertson, M.P.A., *Tobacco Policy Research Program, College of Nursing, University of Kentucky, Lexington, KY*

Seongjik Lee, M.A., *Tobacco Policy Research Program, College of Nursing, University of Kentucky, Lexington, KY*

Suzann L. Vogel, M.P.A., *Tobacco Policy Research Program, College of Nursing, University of Kentucky, Lexington, KY*

Mark J. Travers, Ph.D., *Department of Health Behavior, Roswell Park Cancer Institute, Buffalo, NY*

Corresponding Author:

Kiyoung Lee, Sc.D., *Graduate School of Public Health and Institute of Health and Environment, Seoul National University, 28 Yeungun-dong, Jongro-gu, Seoul 110-460, Korea. Telephone: +82 2 740 8881; Fax: +82 2 745 9104; E-mail: cleanair@snu.ac.kr*

doi: 10.1093/ntr/ntp026

Advance Access publication on April 3, 2009

Received November 20, 2008; accepted January 28, 2009

© The Author 2009. Published by Oxford University Press on behalf of the Society for Research on Nicotine and Tobacco.

All rights reserved. For permissions, please e-mail: journals.permissions@oxfordjournals.org

Tobacco smoke substantially contributes to indoor particle concentration in hospitality venues and can be greatly reduced by implementation of smoke-free air laws (Lee et al., 2008; Lee, Hahn, Riker, Head, & Seithers, 2007; Ott, Switzer, & Robinson, 1996; Repace, 2004; Repace, Hyde, & Brugge, 2006; Semple, Creely, Naji, Miller, & Ayres, 2007; Travers, Cummings, & Hyland, 2004; Valente et al., 2007). When indoor $PM_{2.5}$ levels were measured in six pubs in Boston, the level decreased 96% (Repace et al., 2006). Indoor $PM_{2.5}$ levels decreased 93% in Lexington Kentucky (Lee et al., 2008). Indoor $PM_{2.5}$ level decreased 84% in 20 hospitality venues after the smoke-free air law took effect in western New York (Travers et al., 2004). Indoor $PM_{2.5}$ levels decreased 92% after the smoke-free air law in Scotland (Semple et al., 2007). In Italy, significant decreases in $PM_{2.5}$ and ultrafine particulate (UFP) levels were observed after the indoor smoke-free air law, although reduction of UFP was not as notable as for $PM_{2.5}$ (Valente et al., 2007). When indoor respirable particles were measured in eight hospitality venues in Delaware before and after a statewide smoke-free air law, respirable particle levels decreased 90% and particle bound polycyclic aromatic hydrocarbons decreased 96% (Repace, 2004). The effect of smoke-free laws is not only significant but also immediate. In Georgetown, KY, indoor fine particle concentrations were immediately improved after the smoke-free air law (Lee et al., 2007). These studies demonstrate that comprehensive smoke-free air laws reduce indoor air pollution to safe levels for workers and the public.

While comprehensive smoke-free legislation clearly improves indoor air quality and public health, not all smoke-free air laws are comprehensive, covering all workers and patrons. The purpose of this study was to compare indoor air pollution in venues located in communities with and without comprehensive smoke-free air laws. Indoor air quality of hospitality venues was measured in six Kentucky communities before and after comprehensive smoke-free air laws took effect; in one community before and after partial and comprehensive smoke-free air laws and in two communities after partial smoke-free air laws took effect.

Methods

Monitoring procedures

This study was conducted with hospitality venues including restaurants and bars in a total of nine Kentucky communities. Indoor air quality was measured in seven communities before and after comprehensive smoke-free air laws and in two counties after partial smoke-free air laws. Venues in one community were measured three times; prelaw, after the initial partial law, and after the law was strengthened to cover all workplaces and public places with few exemptions. Purposive sampling was used to identify the venues that allowed smoking. A total of 62 venues were measured in seven communities with comprehensive smoke-free air laws. Twenty one venues were measured in two counties after partial smoke-free air laws were implemented. Indoor $PM_{2.5}$ levels of public venues were measured 156 times in 83 venues in nine communities.

The monitor (Sidepak, TSI) was concealed in either a backpack or a purse and set so that automatic 1-min samples were collected continuously before entering the venue and

during the visit (mean = 43 min). When inside the venue, a central location was selected, as far away as possible from direct puffs of cigarettes or cigars. In large locations, data collection was maintained while walking up and down the establishment, while keeping the monitor about 2–4 ft from the floor. The measurement was corrected by a conversion factor of 0.295 obtained from calibration against gravimetric measurement (Lee et al., 2008).

In addition to air quality measurements, room size, number of persons present, number of burning cigarettes and cigars, description of the venue, temperature, relative humidity, air pressure at entryways, and maximum occupancy were collected. Each venue was measured using a digital ruler for smaller venues (2–50 ft range) or an infrared laser for larger ones (10–700 yd). Total persons in the venue and total number of cigarettes/cigars smoked in each venue were counted at the beginning and at regular interval until the end of the sampling period.

The monitor provided 1-min average $PM_{2.5}$ levels. Arithmetic mean indoor concentration was calculated for each location. Concentrations of $PM_{2.5}$ before and after the smoke-free air law were assessed by Student's *t* test. An analysis of variance (ANOVA) for dependent groups with trend analysis was also performed to identify the determinants of indoor particles and the association between smoking density and indoor particle concentrations. Log-transformed $PM_{2.5}$ values were used in the ANOVA test. Smoking density was classified into three groups, with no smoking, 0–0.5, 0.5–1, and >1 cigarette smoked/100 m³ of room volume.

Results

Indoor air quality in communities with comprehensive smoke-free air laws

Average indoor $PM_{2.5}$ concentrations in each of seven communities with comprehensive laws varied from 84 to 304 $\mu\text{g}/\text{m}^3$ with a mean of 161 $\mu\text{g}/\text{m}^3$, before the laws were implemented (see Table 1). Average smoking density was 0.9 burning cigarettes/100 m³, ranging from 0.1 to 2.3 burning cigarettes/100 m³. After comprehensive smoke-free air laws were implemented in the seven communities, the average indoor $PM_{2.5}$ concentration dropped to 20 $\mu\text{g}/\text{m}^3$, representing an 88% decline in the mean before the law (see Figure 1). We observed smoking in only two of the 62 hospitality venues in seven communities after the comprehensive laws took effect.

Indoor air quality in communities with partial smoke-free air laws

In two communities with partial smoke-free air laws, indoor levels were not measured before the laws took effect. Average indoor $PM_{2.5}$ concentrations in those two communities post-law were 276 and 133 $\mu\text{g}/\text{m}^3$. Even with the partial smoke-free air law, smoking densities were 1.7 and 0.3 burning cigarettes/100 m³, respectively. Smoking was observed in 7 of 10 and 4 of 11 venues in these two communities, respectively. In County I, indoor $PM_{2.5}$ concentrations were significantly different by type of venue, reflecting the specific provisions

Table 1. Indoor PM_{2.5} concentrations in hospitality venues before and after smoke-free air laws in Kentucky

Community	Venue	Average PM _{2.5} before law (μg/m ³)	Average smoking density (#bc/100 m ³) ^a	Average PM _{2.5} after law (μg/m ³)	No. of venues with smoking	Strength of smoke-free air laws
City A	10	148	0.5	28	0	Comprehensive
City B	9	199	2.3	18	1	Comprehensive
City C ^b	9	84	1.2	18	0	Comprehensive
County D ^c	10	304	0.7	9	0	Comprehensive
County E	8	67	0.1	17	0	Comprehensive
County F	10	110	0.3	18	0	Comprehensive ^d
County G	6	214	0.9	32	1	Comprehensive
County H	10	NA	NA	276	7	Partial
County I	11	NA	NA	133	4	Partial
County D	10	304	0.7	338	7	Partial

Note. County D had a partial smoke-free air laws and then strengthened the law to cover all workplaces and enclosed public places. NA, not available.

^aNumber of burning cigarettes/100 m³ of room volume.

^bThe result was published in Lee et al. (2007).

^cThe result was published in Lee et al. (2008).

^dSmoking allowed in designated employee break rooms; two work-sites applied for the exemption and they were not included in the air quality testing.

of the policy. The average indoor PM_{2.5} concentration in smoke-free restaurant locations was 10 μg/m³. The indoor air pollution in bars, which were exempt from the law, was 235 μg/m³.

In County D, indoor air quality was assessed before and after implementation of a partial smoke-free air law and then again after implementation of a comprehensive smoke-free air law. The average PM_{2.5} prelaw level from 10 venues was 304 μg/m³. After a partial smoke-free air law was implemented, the average PM_{2.5} level rose slightly to 338 μg/m³ in the 10 venues (see Figure 2), even though 3 of the 10 venues were smoke-free as a result of the law. After the comprehensive smoke-free air law was implemented, the average PM_{2.5} level dropped substantially to 9 μg/m³, with all 10 venues being smoke-free (see Figure 2).

After implementation of the comprehensive smoke-free air law, levels ranged from 7 to 12 μg/m³.

Factors associated with indoor fine particle levels

Only smoking density was associated with indoor PM_{2.5} levels. Several variables, like county, type of venue, size of venue, and average number of patrons, were not associated with indoor PM_{2.5} levels. When smoking density was classified into four groups, a clear linear trend was observed with increasing indoor fine particles as a greater number of cigarettes were burned ($F=26.94, p<.0001$). The relationship between smoking density and indoor PM_{2.5} level is shown in Figure 3. The mean indoor PM_{2.5} level was 333 μg/m³ when more than one cigarette was

Figure 1. Decline in indoor fine particles after comprehensive smoke-free air laws in 7 cities/counties of Kentucky.

Figure 2. Difference in indoor air quality between partial and comprehensive laws in County D.

burned in a 100 m³-sized room, 291 µg/m³ when 0.5–1 cigarette was burned, and 125 µg/m³ when fewer than 0.5 cigarette was burned. When no smoking was observed, the mean indoor PM_{2.5} level was 25 µg/m³.

During the monitoring, we counted number of patrons in the venues. When the comprehensive laws were implemented and no indoor smoking was observed, the number of patrons was not associated with indoor PM_{2.5}. There were fewer patrons observed in 27 venues; while more patrons were observed in 35 venues after the comprehensive laws. The change in number of patrons was not significant after implementation of comprehensive smoke-free air laws (paired *t* test, *t* = .175, *p* = .35). There was a slight variation in number of patrons by venue type; 67% of restaurants had more patrons and 54% of other entertainment venues had fewer patrons after the law. Change in number of patrons after the partial laws was not available because we did not measure indoor air quality before the law.

Discussion

The average PM_{2.5} level in 62 hospitality venues in communities before they had smoke-free air laws was 161 µg/m³. The level was 6.4 times higher than the World Health Organization guideline level for 24-hr exposure of 25 µg/m³ (World Health Organisation [WHO], 2006). The level was also 4.6 times higher

than the National Ambient Air Quality Standard (NAAQS) for outdoor air set by the Environmental Protection Agency (EPA). To protect the public's health, the EPA set a new limit of 35 µg/m³ on 17 December 2006 as the average level of exposure more than 24 hr in *outdoor environments* (U.S. Environmental Protection Agency, 2006). There is no EPA standard for indoor air quality. Assuming a background level of 20 µg/m³, 24-hr worker exposure is estimated to be 67 µg/m³ (=161 µg/m³ × 8/24 hr + 20 µg/m³ × 16/24 hr). This level violates the NAAQS by a factor of 1.9. For patrons during a 3-hr visit, the violation is about 7.5% higher than the NAAQS.

Indoor air quality can be improved by implementation of comprehensive smoke-free air laws, while partial smoke-free air laws did not affect indoor air quality. Indoor air quality was improved by 88% after comprehensive smoke-free air laws were implemented. The average indoor PM_{2.5} level of 20 µg/m³ was below the WHO guideline and the NAAQS. In two communities with partial smoke-free air laws, average indoor PM_{2.5} concentrations were 276 and 133 µg/m³. Since we did not measure before the laws, we could not determine change in air quality after these laws. The indoor PM_{2.5} levels with partial laws were 11 and 5.3 times higher than the WHO guideline and the NAAQS, respectively.

Compliance with smoke-free air laws is critical to achieving the goal of eliminating exposure to SHS. Nearly, all (96.8%) hospitality venues measured in this study including bars complied with the comprehensive smoke-free air laws. This non-compliance rate is similar to California where one of the earliest smoke-free air laws was implemented (Weber, Bagwell, Fielding, & Glantz, 2003).

Effects of comprehensive smoke-free air laws on indoor air quality and public health are clear. However, the opposition to smoke-free regulations often seeks compromise resulting in enactment of partial smoke-free air laws with multiple exemptions. Our findings demonstrated that venues located in communities with partial laws did not show improvement in indoor air quality after implementation of the laws. In all communities with partial laws, indoor PM_{2.5} levels postlaw were significantly higher than the WHO guideline. Similar results were observed in Europe (Lopez et al., 2008). The measured median nicotine concentra-

Figure 3. Association between smoking density and indoor air quality in Kentucky. Smoking density refers to burning cigarettes/100 m³ room volume.

tions in Ireland with comprehensive smoke-free laws were the lowest. The nicotine levels were not significantly lower in countries with restricted smoke-free air laws.

The best example of the association between strength of smoke-free air laws and indoor air quality is County D. The average $PM_{2.5}$ prelaw level from 10 venues was $304 \mu g/m^3$. After passing a partial smoke-free air law, County D workers and patrons remained exposed to dangerous air pollution levels. Indoor air pollution levels after the partial law were approximately 9.7 times higher than the NAAQS. After implementation of a comprehensive smoke-free air law, however, the level of indoor air pollution in County D hospitality and entertainment venues fell well below the NAAQS. This demonstrates that comprehensive smoke-free air laws reduce indoor air pollution to safer levels for workers and the public.

The only factor related to indoor $PM_{2.5}$ level was the presence of indoor smoking. When there was no smoking observed, indoor $PM_{2.5}$ was $21 \mu g/m^3$. When smoking was observed, the indoor $PM_{2.5}$ level was $226 \mu g/m^3$. Indoor $PM_{2.5}$ can be generated by several other sources. In hospitality venues, possible sources include cooking, human activity (i.e., cleaning), and outdoor air pollution. Cooking and human activity may be associated with occupant density, as more people in the venue may increase such activities. However, in this study, only smoking density, estimated by the number of burning cigarettes/100 m^3 , was significantly associated with indoor $PM_{2.5}$. Associations between smoking density and indoor $PM_{2.5}$ levels were clearly demonstrated, showing that the difference in $PM_{2.5}$ levels before and after the smoke-free air laws was due to smoking.

The opposition often claims that smoke-free air laws result in economic harm to businesses. However, many well-designed studies have demonstrated no impact or a positive impact of smoke-free laws on sales or employment of restaurant and bar (Scollo, Lal, Hyland, & Glantz, 2003). Our study showed that the number of patrons observed during air quality monitoring did not change after comprehensive laws were implemented. We were not able to compare numbers of patrons in the communities with partial laws because we measured only one county before and after a partial law. While these observations are not an economic indicator, the data are consistent with the multitude of economic impact studies showing no economic harm from smoke-free air laws (Glantz & Smith, 1997; Pyles, Mullineaux, Okoli, & Hahn, 2007). In addition, smoke-free laws have been associated with a reduction in population levels of serum cotinine among non-smokers and have also contributed to a reduction in overall cigarette consumption among smokers, with no adverse economic impact, except to the tobacco industry (Eriksen & Cerak, 2008). Such findings can reassure policymakers and instill confidence in rejecting industry claims of an adverse economic impact.

Significant reductions in indoor air pollution were demonstrated in venues covered by comprehensive smoke-free municipal laws. Further, indoor air pollution in communities with partial laws was 12.5 times higher than in communities with comprehensive laws. However, we did not measure indoor $PM_{2.5}$ levels in the two communities with partial laws before implementation. Although we do not know the impact of the partial laws on indoor air quality, it is clear that partial laws are not as effective in reducing indoor air pollution as are comprehensive smoke-free air laws. These findings lend further support

for the enactment of comprehensive smoke-free laws at local and state levels and the avoidance of partial laws that have no impact on population exposure to SHS.

Funding

The Robert Wood Johnson Foundation Developing Leadership in Reducing Substance Abuse Program (4-68555); American Cancer Society Mid-South Division; Kentucky Department for Public Health (PO2 722 0800015267 1); Foundation for a Healthy Kentucky (2007ADV002); National Institutes of Health/National Heart, Lung and Blood Institute (R01 HL086450-01).

Declaration of Interests

None declared.

Acknowledgments

The work was performed at the University of Kentucky.

References

- American Nonsmokers Rights Foundation. *Overview list—How many smokefree laws?* Retrieved January 1, 2009, from <http://www.no-smoke.org/pdf/mediaordlist.pdf>.
- Eriksen, M. P., & Cerak, R. L. (2008). The diffusion and impact of clean indoor air laws. *Annual Review of Public Health*, 29, 171–185.
- Glantz, S. A., & Smith, L. R. A. (1997). The effect of ordinances requiring smoke-free restaurants and bars on revenues: A follow-up. *American Journal of Public Health*, 87, 1687–1693.
- Lee, K., Hahn, E. J., Pieper, N., Okoli, C. T. C., Repace, J., & Troutman, A. (2008). Differential impacts of smoke-free laws on indoor air quality. *Journal of Environmental Health*, 70, 24–30.
- Lee, K., Hahn, E. J., Riker, C., Head, S., & Seithers, P. (2007). Immediate impact of smoke-free laws on indoor air quality. *Southern Medical Journal*, 100, 885–889.
- Lopez, M. J., Nebot, M., Albertini, M. M., Birkui, P., Centrich, F., Chudzikova, M., et al. (2008). Secondhand smoke exposure in hospitality venues in Europe. *Environmental Health Perspectives*, 116, 1469–1472.
- Ott, W., Switzer, P., & Robinson, J. (1996). Particle concentrations inside a tavern before and after prohibition of smoking: Evaluating the performance of an indoor air quality model. *Journal of the Air & Waste Management Association*, 46, 1120–1134.
- Pyles, M. K., Mullineaux, D. J., Okoli, C. T. C., & Hahn, E. J. (2007). Economic effect of a smoke-free law in a tobacco-growing community. *Tobacco Control*, 16, 66–68.
- Repace, J. (2004). Respirable particles and carcinogens in the air of Delaware hospitality venues before and after a smoking ban. *Journal of Occupational and Environmental Medicine*, 46, 887–905.

- Repace, J. L., Hyde, J. N., & Brugge, D. (2006). Air pollution in Boston bars before and after a smoking ban. *BMC Public Health*, 6, 266.
- Scollo, M., Lal, A., Hyland, A., & Glantz, S. (2003). Review of the quality of studies on the economic effects of smoke-free policies on the hospitality industry. *Tobacco Control*, 12, 13–20.
- Semple, S., Creely, K. S., Naji, A., Miller, B. G., & Ayres, J. G. (2007). Secondhand smoke levels in Scottish pubs: The effect of smoke-free legislation. *Tobacco Control*, 16, 127–132.
- Travers, M. J., Cummings, A., & Hyland, A. (2004). Indoor air quality in hospitality venues before and after implementation of a clean indoor air law—Western New York, 2003. *MMWR Morbidity and Mortality Weekly Report*, 53, 1038–1041.
- U.S. Department of Health and Human Services. (2006). *The Health Consequences of Involuntary Exposure to Tobacco Smoke: A Report of the Surgeon General*. Atlanta, GA: Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Center for Chronic Disease and Prevention and Promotion, Office of Smoking and Health.
- U.S. Environmental Protection Agency. (2006). National ambient air quality standards for particulate matter: Final rule. *Federal Register*, 71, 61144–61233.
- Valente, P., Forastiere, F., Bacosì, A., Cattani, G., Di Carlo, S., Ferri, M., et al. (2007). Exposure to fine and ultrafine particles from secondhand smoke in public places before and after the smoking ban, Italy 2005. *Tobacco Control*, 16, 312–317.
- Weber, M. D., Bagwell, D. A. S., Fielding, J. E., & Glantz, S. A. (2003). Long term compliance with California's Smoke-Free Workplace law among bars and restaurants in Los Angeles County. *Tobacco Control*, 12, 269–273.
- World Health Organization. (2006). *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of risk assessment*. Geneva, Switzerland: World Health Organization.