The Impact of Massachusetts' Smoke-Free Workplace Laws on Acute Myocardial Infarction Deaths

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Objectives. We examined the rate of acute myocardial infarction (AMI) deaths in Massachusetts before and after the implementation of a comprehensive smoke-free workplace law in July 2004.

Methods. We used Poisson regression models to examine the impact of the state law in cities and towns with and without previous local smoking bans and the effect of the local laws for the period of 1999 through 2006.

Results. The AMI mortality rate decreased by 7.4% (95% confidence interval [CI]=3.3%, 11.4%) after implementation of the state law. The state ban had an impact in cities and towns with no prior local smoking ban (9.2% decrease; $P<.001$) but not cities and towns with a prior local smoking ban. However, there was a nonsignificant 4.9% (95% CI=–5.0%, 13.9%) decrease associated with the local smoking ban that preceded the effect of the state ban. The effect of the state ban was modest (–1.6%) in the first 12 months after implementation but much larger after the first 12 months (–18.6%; $P<.001$).

Conclusions. Comprehensive statewide smoke-free workplace laws in Massachusetts were associated with an estimated 270 fewer AMI deaths per year. These results add to the evidence suggesting that smoke-free air laws are associated with lower rates of AMI. (*Am J Public Health.* 2010;100:2206–2212. doi:10.2105/AJPH.2009.189662)

Comprehensive smoking bans prohibit smoking in workplaces, including public and private worksites, restaurants, and bars. Studies have shown that comprehensive smoking bans reduce exposure to environmental tobacco smoke, whereas smoking restrictions, which permit designated smoking areas or provide separately ventilated sections, are not effective at preventing or eliminating exposure to environmental tobacco smoke.[1]

In addition to reducing exposure to environmental tobacco smoke, comprehensive smoking bans may change social norms regarding the acceptability of smoking in a community, resulting in fewer people smoking in public places.[1] Comprehensive smoking bans have been shown to reduce smoking prevalence by 3.8% (95% confidence interval [CI]=2.8%, 4.7%) and to reduce the number of cigarettes smoked per smoker per day by 3.1 (95% CI=2.4, 3.8).[2]

Both cigarette smoking and exposure to environmental tobacco smoke increase the risk of coronary heart disease (CHD).[1] It is hypothesized that a decrease in these exposures as a result of a comprehensive smoking ban would result in reductions in CHD. The association between comprehensive smoking bans and acute myocardial infarction (AMI) hospital admissions was examined previously in the United States and Europe. Several meta-analyses have been conducted that pooled the results of these studies and found that comprehensive smoking bans were associated with a 17% to 19% lower AMI hospital admission rate.[3–5]

The first comprehensive workplace smoking ban in Massachusetts was implemented in 1994 in the town of Amherst.[6] Individual cities and towns enacted comprehensive smoking bans over the next decade. In 2003, Boston, Cambridge, and Somerville implemented comprehensive smoking bans. All residents of Massachusetts were covered by the state comprehensive smoking ban in July 2004, which banned smoking in all workplaces, including restaurants and bars.[7]

The experience in Massachusetts, in which local laws introduced comprehensive workplace smoking bans at various times, offers the opportunity to assess the impact of the local and statewide laws both separately and jointly. We examined the AMI mortality rate before and after the Massachusetts smoke-free air law in cities and towns with and without prior local comprehensive smoking bans. We also examined the impact of the local smoking bans before the statewide smoke-free law took effect.

METHODS

These analyses were restricted to Massachusetts residents aged 35 years and older, which reflected the population at risk for AMI. Although we examined AMI deaths from 1999 to 2006, a single population at risk (n=3 342 917) was obtained from the 2000 US Census.[8] Although Massachusetts conducts a yearly census count in each of the 50 cities, these data are not available for the 301 towns.

Death From Acute Myocardial Infarction

Death records were obtained from the Massachusetts Registry of Vital Records and Statistics for the period of January 1, 1999, through December 31, 2006. The records included the date of death, primary and secondary causes of death, age, gender, town or city of residence, town or city in which the death occurred, and whether the death occurred in a hospital setting or elsewhere. The smoking status of the decedent was not reported. The sample was restricted to AMI deaths (primary cause *International Classification of Diseases, 10th Revision*, code I21) among those 35 years of age or older. Deaths were assigned to a decedent's city or town of residence.

Smoke-Free Workplace Laws

The extent and effective dates of local smoke-free workplace laws in each of the 50 cities and 301 towns in Massachusetts were characterized on the basis of data provided by the Massachusetts Department of Public Health and confirmed by the American Nonsmokers

Rights Foundation.[6] We defined a comprehensive smoking ban, hereafter referred to as a smoking ban, as a law that specifically banned smoking in 5 physical environments: restaurants, bars, municipal buildings, publicly accessible spaces, and all work spaces not accessible by the public. For example, a law that banned smoking in restaurants but not bars was not considered comprehensive.

Some cities or towns passed laws in increments. For example, the town of Holliston passed a smoke-free workplace and restaurant law in 1999, but a smoke-free bar law was not passed until 2002. Thus, we defined the date of a comprehensive smoke-free workplace law on the basis of the last date that a smoke-free law was passed in each city or town.

The 351 Massachusetts cities and towns were divided into 2 groups: the 61 cities and towns (population 835 597) that had implemented a smoking ban before the state law took effect and the 290 cities and towns (population 2 507 320) that had no smoking restrictions or had noncomprehensive smoking restrictions before the state law took effect.

Covariates

We identified time-varying risk factors for AMI, including long-term trend, season,[9] particulate matter less than 2.5 μm aerodynamic diameter ($PM_{2.5}$),[10–12] and influenza.[13,14] We assumed a linear decrease in AMI deaths with time, plus a seasonal pattern modeled by annual and semiannual sine and cosine terms.[15,16] Daily $PM_{2.5}$ data were obtained at the county level from the Massachusetts Department of Environmental Protection. Missing $PM_{2.5}$ values were replaced with the average of 2 adjacent records or with data from the nearest monitoring site. The Massachusetts Department of Public Health gathered weekly data on the number of "influenza-like illnesses" reported during flu season. Influenza data for 1999 and 2000 were missing information for summer months. Missing flu data were assumed to be the average reported during summer months for the other years studied.

In addition, city- and town-specific demographic characteristics considered to be associated with AMI death or implementation of the smoking ban were obtained from the 2000 US Census.[8] The variables included median age, average household size, percentage multiunit housing, percentage unemployed, median household income, percentage with incomes below the federal poverty level (200%), percentage with a college degree, percentage disabled, percentage foreign born, and percentage married.

Statistical Analysis

We first examined the impact of the Massachusetts statewide ban on AMI mortality rates. Second, we examined the effect of equivalent local bans enacted before the statewide ban plus the interactive effects of the state and local bans. Finally, we examined the timing of changes in AMI deaths in response to smoking bans.

Each of these questions was examined by using a Poisson regression model. The outcome for each model was the daily number of deaths from AMI by city or town. Each model was adjusted for population by including the city- or town-specific population aged 35 years and older as an offset in the models. All models were adjusted for a linear time term from 1999–2006, season, $PM_{2.5}$, influenza epidemics, and city- or town-specific demographic factors. We additionally included a random intercept term in each model by using the GLIMMIX macro in SAS version 9.1.[17] The percentage change in the AMI mortality rate was calculated as the rate ratio minus 1 multiplied by 100.

The first model compared city- and town-specific AMI mortality rates after implementation of the state law with the rates before the state law by including an indicator variable for the period after the state comprehensive ban (after July 5, 2004). This model was run for all Massachusetts residents aged 35 years and older and in separate models by gender, age group, and prior local smoking ban status.

Second, we estimated the impact of the local smoking bans before the state law by including an indicator variable for the period after the local law. For this analysis, we restricted the analysis to cities and towns that had a local smoking ban before the state law and examined only the time period before the state law took effect.

Third, for all cities and towns, we estimated the effect of the state law in cities and towns with and without a prior smoking ban. This was examined by using an interaction term (prior smoking ban×state law).

Finally, given the evidence of increasing impacts over time, we estimated the impact of the state law within 12 months and after 12 months of the state law in cities and towns that had not implemented a smoking ban before the state law.

To evaluate the timing of the state and local smoking bans on AMI mortality rates, we calculated the cumulative sum[18] of observed AMI mortality rates minus expected monthly age- and gender-standardized rates. We calculated expected rates on the basis of a fit of the observed rates before the state or local smoking ban to a linear trend and seasonal predictors (annual and semiannual sines and cosines). The cumulative sum was calculated for cities and towns without a comprehensive smoking ban and for 25 cities and towns that had implemented local smoking bans between May 2003 and June 2004.

The annual number of fewer deaths that was associated with the state smoking ban was calculated as the observed number of deaths per year before the ban times the estimated percentage decrease associated with the state smoking ban.

RESULTS

There were 26 982 AMI deaths in the 351 Massachusetts cities and towns from January 1, 1999, through December 31, 2006, which constituted an average of 100.9 AMI deaths per 100 000 population (35 years and older) per year. Crude AMI annual mortality rates were 25% lower after the implementation of the state smoking ban than before (Table 1).

Monthly AMI mortality rates showed a strong seasonal pattern and a downward trend with time (Figure 1). Expected monthly values based on the period before the state ban were extrapolated to the months after the ban (Figure 1). After the state ban, the crude AMI mortality rates were lower than expected, starting approximately 1 year after implementation of the law.

The change in AMI mortality rates after the state ban, adjusted for linear trend, season, influenza, fine particle air pollution, demographic characteristics, and city or town, was substantially reduced compared with the crude difference (7.4%) but still highly statistically significant (Table 1). The adjusted effect of the state ban was larger for women (9.7%) than for men (5.1%), although this difference was not

TABLE 1—AMI Mortality Rate for Massachusetts Residents Aged 35 Years and Older Before and After Implementation of the Comprehensive State Ban on Smoking: Massachusetts, 1999-2006

	Total		AMI Mortality Rate (per 100 000 persons)		% Change		
	Population	No. of AMI Deaths	Before State Ban	After State Ban	Crude Change	Adjusted Change[a] (95% CI)	P
Total	3 342 917	26 982	109.2	82.5	–24.5%	–7.4% (–11.4%, –3.3%)	<.001
Age, y							
35–64	2 482 755	4162	22.2	18.1	–18.5%	–7.6% (–17.7%, 3.8%)	.19
65–74	427 830	4657	151.2	102.5	–32.2%	–1.0% (–11.3%, 10.6%)	.86
≥75	432 332	18 163	567.1	432.2	–23.8%	–9.1% (–13.9%, –4.1%)	<.001
Gender							
Men	1 548 463	13 595	117.9	91.7	–22.3%	–5.1% (–10.9%, 1.0%)	.097
Women	1 794 454	13 387	101.7	74.5	–26.7%	–9.7% (–15.1%, –3.9%)	.001
Prior local smoking ban in effect[b]							
No	2 507 320	20 806	112.7	83.8	–25.7%	–9.9% (–14.3%, –5.3%)	<.001
Yes	835 597	6176	98.7	78.5	–20.5%	1.4% (–7.6%, 11.3%)	.77

Note. AMI = acute myocardial infarction; CI = confidence interval. The AMI mortality rate is the average annual AMI mortality rate per 100 000 persons. The comprehensive state smoking ban was implemented in July 2004.
[a]Adjusted for trend, season, influenza, fine particle air pollution, town-specific demographics, and a random intercept for each city or town.
[b]Prior local comprehensive smoking ban similar to the state law.

statistically significant. There was also no statistically significant difference in the effect of the ban by age category (Table 1).

Before the implementation of the state ban in July 2004, local smoking bans had been implemented in 61 cities and towns (Figure 1). For example, a comprehensive workplace smoking ban was implemented in Boston, the largest city (population 589 141), in May 2003. Thus, although 100% of the state population was covered in July 2004, only 25.0% was covered in June 2004 (just before the state law was implemented) and just 7.9% in April 2003 (just before the Boston law was implemented).

We found that the effect of the state ban was observed in the 290 cities and towns without a prior local smoking ban (–9.9%; $P<.001$), with no decrease associated with the state ban in the 61 cities and towns with a prior law (1.4%; $P=.77$; Table 1).

We examined the impact of local smoking bans on AMI mortality rates, in the period before the state ban was implemented, in the 61 cities and towns with a prior local ban. After adjustment for linear and seasonal trends, influenza, fine particles, demographic characteristics, and clustering by city, the AMI mortality rate decreased nonsignificantly by 4.9% (95% CI=–5.0%, 13.9%; $P=.32$) after the local comprehensive smoking ban was implemented.

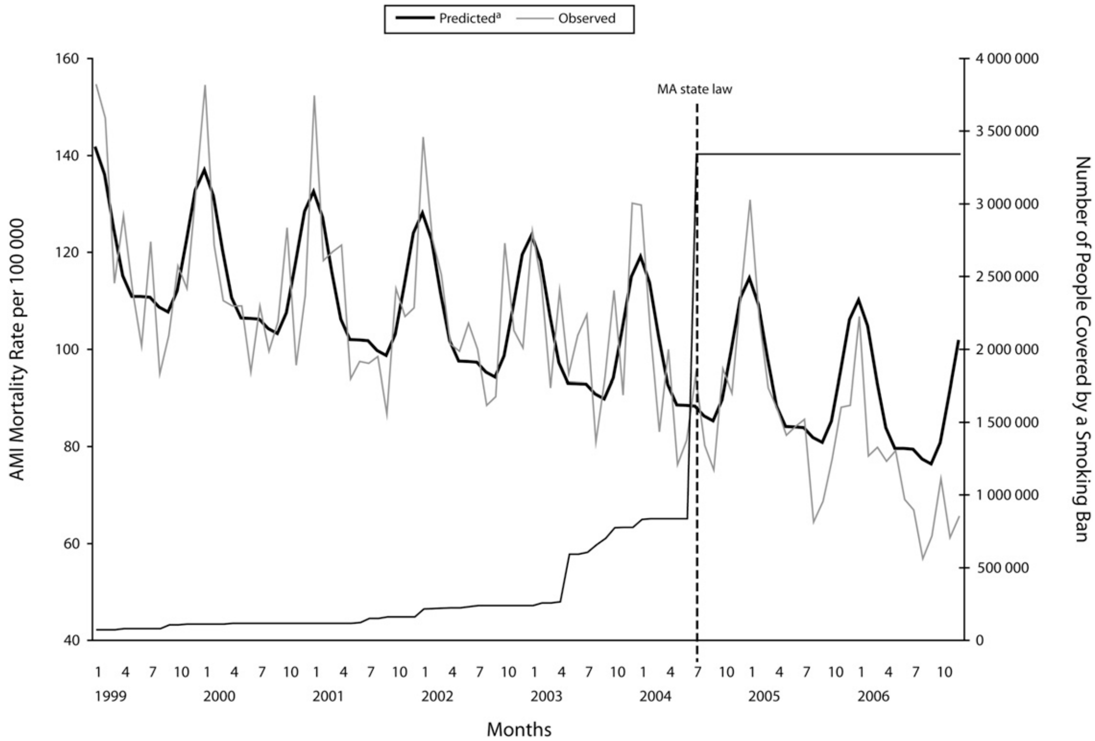
In a combined analysis including all cities and towns and the entire 1999–2006 period, we examined the impact of the local and state smoking bans together (Table 2). In cities and towns that had no prior local ban, there was a 9.2% ($P<.001$) decrease in AMI mortality rates after implementation of the state ban. Among cities and towns that had a local smoking ban, there was a 2.9% ($P=.41$) decrease after the local ban, but no decrease after the state smoking ban (–0.7%; $P=.87$). The interaction between the state and local smoking bans was significant ($P=.03$). We estimated that AMI death rates decreased by 7.4% (95% CI=3.4%, 11.3%; $P<.001$) after any comprehensive smoking ban, whether local or state.

We also examined the timing of the impact of the state and local smoking bans by using the cumulative sum analysis of observed monthly versus expected AMI mortality rates (Figure 2). Among cities and towns without a prior local smoking ban, the cumulative sum of AMI mortality rates decreased immediately after the state ban, with an accelerated decrease approximately 12 months after the state law. Twenty-five cities and towns (17% of the state population) implemented local smoking bans in the 13 months before the state ban (May 2003–June 2004). The cumulative sum of AMI mortality rates in these cities and towns decreased earlier than did the cumulative sum for those without a local ban (Figure 2), but approximately 8 months after the Boston smoking ban was implemented in May 2003. There was a parallel decrease in the cumulative sum of AMI mortality rates among cities and towns with and without a local smoking ban.

Given this apparent effect of the smoking bans approximately 1 year after implementation of the ban, we estimated the change in AMI mortality rates for the cities and towns with no prior local ban separately for the first and second 12 months after the state ban, adjusting for trend, season, influenza, air pollution, demographics, and city or town. In the first 12 months after the state ban, AMI mortality rates decreased by 1.6% (95% CI=–4.0%, 7.0%; $P=.56$), whereas after the first 12 months, rates decreased by 18.6% (95% CI=13.6%, 23.3%; $P<.001$). On the basis of the overall adjusted effect of the state smoking ban of 7.4% (Table 1), we estimated that there were 270 (95% CI=120, 416) fewer AMI deaths per year associated with the state ban.

DISCUSSION

Massachusetts implemented a comprehensive smoking ban on July 5, 2004, that prohibited smoking in all worksites, including



Note. The number of Massachusetts residents covered by a comprehensive smoking ban is shown on the right x-axis.
[a]Predicted mortality rates were adjusted for trend and season.

FIGURE 1—Observed and predicted monthly acute myocardial infarction mortality rates per 100 000 persons in Massachusetts: 1999–2006.

restaurants and bars. We found a statistically significant 7.4% (95% CI=3.3%, 11.4%) decrease in the AMI mortality rates associated with the Massachusetts state smoking ban.

Before the implementation of the state smoke-free workplace law, approximately 25% of the Massachusetts population was covered by a local smoking ban. Local smoking bans were associated with a nonsignificant 4.9% (95% CI=−5.0%, 13.9%) decrease in the AMI mortality rate. The state smoke-free workplace law did not further reduce the AMI mortality rates in those cities and towns with a prior ban. Among cities and towns without a local smoking ban, by contrast, there was a statistically significant 9.2% (95% CI=4.8%, 13.4%) decrease in the AMI mortality rates associated with the state smoke-free workplace law.

Our results are consistent with previous findings showing lower hospitalization rates for AMI after the implementation of comprehensive smoking bans. Among the 11 published, peer-reviewed studies that have examined this association,[5] our study is most similar to a study in New York State in which smoking bans were implemented in certain counties before the implementation of the New York state law.[19] Those authors found a similar decrease of 8% in AMI hospitalization rates associated with the New York state comprehensive smoking ban.[19]

The results of the cumulative sum analysis indicated a slight reduction in AMI mortality rates immediately after the state law in cities and towns without local comprehensive smoking bans and a steeper reduction starting 1 year after the state law. Among cities and towns that had implemented local smoking bans between May 2003 and June 2004 (such as Boston, Cambridge, and Somerville), AMI mortality rates decreased approximately 8 months after the Boston law was implemented.

In previous studies that examined the time period for a reduction in AMI hospitalization rates, larger reductions were generally seen within 1 year after the implementation of the smoking ban.[20–22] A recent meta-analysis reported a reduction of 17% (95% CI=13%, 20%) in AMI hospital admissions 12 months after the implementation of a law.[4] Both this meta-analysis and another meta-analysis reported that reductions in AMI hospitalizations increase with time.[4,5] The smaller reduction in AMI deaths found during the first year after the smoking bans in our study may have been because we examined AMI mortality rates rather than hospitalization rates.

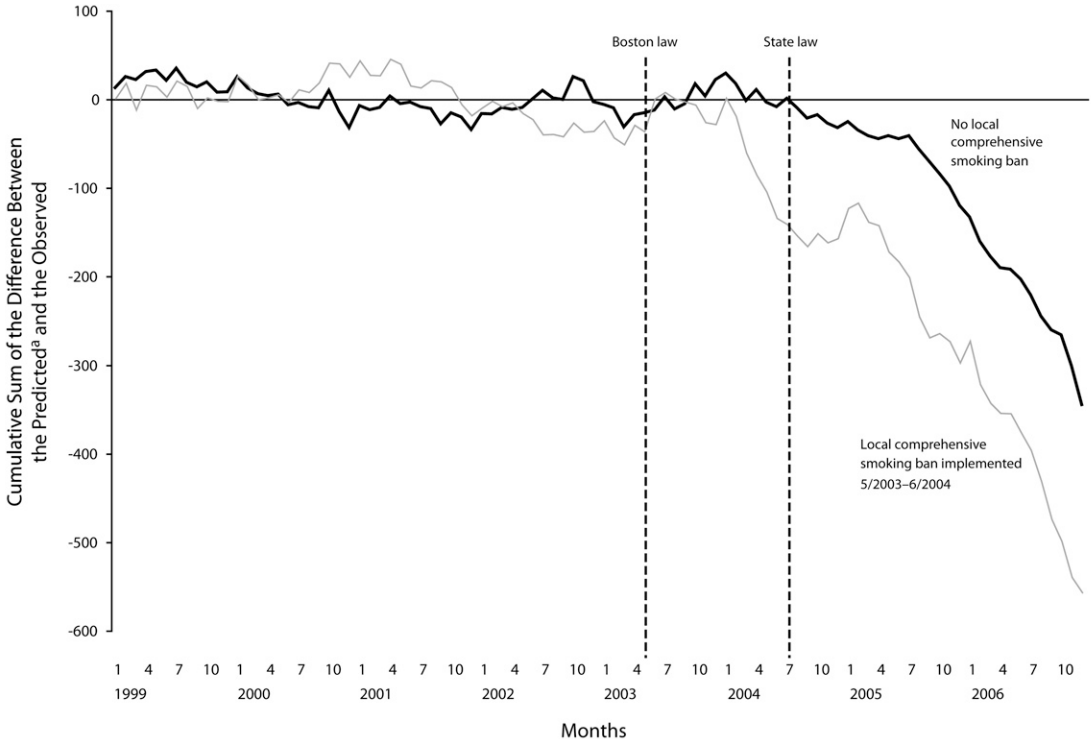
Thirty percent of female patients and 20% of male patients who experience heart attacks die within 12 months.[23] Therefore, whereas AMI hospitalizations are immediate, some AMI deaths may be delayed. Other potential explanations for the observed decrease in AMI mortality rates include an increase in the Massachusetts cigarette sales tax (July 2002),[24] the installation of cardiac defibrillators in public areas (starting in 1995), a new definition for myocardial infarction (2000),[25] and other legislation associated with AMI, such as the Massachusetts Medicare Cholesterol Screening Coverage Act (2003).[26] However, the timing of these events is not consistent with the observed decrease in AMI mortality rates.

TABLE 2—Percentage Change in AMI Mortality Rates After the Implementation of Local or State Comprehensive Smoking Bans Compared With Before the Ban: Massachusetts, 1999–2006

			% Change in AMI Mortality Rates[a]			
Prior Local Comprehensive Ban in Effect[b]	Population Aged ≥35 y	No. of AMI Deaths	After Local Ban, % (95% CI)	*P*	After State Ban, % (95% CI)	*P*
Yes (61 cities and towns)	835 597	6176	−2.9% (−9.6%, 4.3%)	.41	−0.7% (−8.2%, 7.5%)	.87
No (290 cities and towns)	2 507 320	20 806	...	...	−9.2% (−13.4%, −4.8%)	<.001

Note. AMI = acute myocardial infarction; CI = confidence interval. The comprehensive state smoking ban was implemented in July 2004.
[a]Adjusted for trend, season, influenza, fine particle air pollution, town-specific demographics, and a random intercept for each city or town.
[b]Prior local comprehensive smoking ban similar to the state law.

Reductions in environmental tobacco smoke were reported after implementation of both the Boston ban and the state smoke-free air law.[27–30] A random sample of 40 bars in Boston were observed up to 1 month before the Boston ban (April 12 to May 1, 2003) and up to 3 months after the ban (May 7 to July 30, 2003). The mean proportion of patrons smoking inside those bars decreased from 22.5% to 0.2%.[27] Another study in Boston sampled 7 bars and restaurants 1 month before and 6 months after the smoke-free air law was implemented. Respirable suspended particles decreased by 95% after the ban.[28] After the Massachusetts state smoke-free air law took effect, respirable suspended particles were measured in a convenience sample of 27 bars and restaurants located in 5 Massachusetts cities without a smoking ban before the state law. Approximately 5 months after the law, respirable suspended particles decreased by 93% compared with the month before the law.[30] Although the latter 2 studies used convenience samples, which may not represent the status of environmental tobacco smoke exposure in all bars and restaurants or all workplaces, the studies did consistently show a decrease in environmental tobacco smoke



Note. For cities and towns with no local smoking ban, rates were predicted by using data up until the state law took effect (July 2004). For cities and towns with laws implemented from May 2003–June 2004, rates were predicted by using data up until the Boston law took effect (May 2003).
[a]Predicted mortality rates were adjusted for trend and season.

FIGURE 2—Cumulative sum of the difference between the monthly average acute myocardial infarction mortality rate (age- and gender-standardized) and the predicted mortality rate: Massachusetts, 1999–2006.

exposure after the Boston and Massachusetts smoking bans.

Compliance with the Massachusetts state law was found to be 96.3% in a 2005 sample of Massachusetts bars and restaurants.[30] Evaluations by local boards of health and the Massachusetts Association of Health Boards, which included a larger sample of bars and restaurants, found compliance to be between 88% and 91% during the year after the state law.[31] Compliance with the local comprehensive smoking ban in Boston was at least 91%, according to a 2004 study.[27]

Several limitations of our study should be noted. Exposure misclassification may have occurred in examining the impact of the local smoking bans. Before the implementation of the Massachusetts state smoke-free air law, an adult may have lived in a city or town with a local comprehensive smoking ban but worked or spent leisure time in a city or town without a ban. This misclassification is not likely related to AMI mortality, thus biasing the results toward the null.

In addition, inaccuracies may have existed in using death certificates as a measure of death from AMI. Death certificates were not verified by using medical records or autopsy information. A previous study using data from the Framingham Heart Study, which was based in Massachusetts, compared death certificates coded for coronary heart disease to assignment of death by 3 physicians.[32] The sensitivity was 83.8% and the specificity was 84.1%. When cause of death was unknown, the death certificate assigned coronary heart disease to 51% of cases. Therefore, death certificates may over-represent AMI as the cause of death. Most likely this over-representation of AMI deaths was not associated with the smoking ban status and would therefore bias the results toward the null.

We were not able to account for the changing population over time. The population aged 35 years and older in Massachusetts increased 5.5% from 3 342 917 in 2000 to 3 527 509 in 2006.[33] Because we assumed that the population stayed the same from 1999–2006, we may have slightly overestimated the AMI mortality rates. However, the population changed by 0.6% to 0.7% each year from 2003 to 2006; thus, there was neither a large increase or decrease in the population that corresponded to the time we saw a decrease in the AMI mortality rates.

Our dataset did not include individual smoking history, so it cannot be determined whether the observed decline in AMI rates was caused by a reduction in environmental tobacco smoke exposure or a reduction in smoking prevalence. A recent study examined the decrease in hospital admissions for acute coronary syndrome after the implementation of smoke-free legislation in Scotland and found that 67% of the decrease involved nonsmokers.[22]

After the Massachusetts state law, there was a 93% reduction in environmental tobacco smoke exposure[30] and a 5.2% reduction in the percentage of current smokers (19.1% in 2003 to 18.1% in 2005),[34] which suggests that the reduction in deaths was more likely associated with a reduction in environmental tobacco smoke exposure.

The large number of AMI deaths (26 982) allowed for adjustment for several potential confounders, including season, time trends, $PM_{2.5}$, and influenza epidemics. Differences between towns were adjusted for by including town-level covariates as well as a random intercept for each town, which allowed a different baseline AMI mortality rate for each town. However, because covariate information was assessed at the town level and not at the individual level, some residual confounding is possible.

Approximately 1 year after the enactment of either a local or a state smoke-free workplace law, there was a substantial decrease in AMI mortality in Massachusetts, resulting in approximately 270 fewer deaths from AMI than expected. With the accumulating evidence of the health benefits associated with smoke-free air laws, more US states are passing such laws. Although great strides have been made, a total of just 22 states, Puerto Rico, and Washington, DC (covering 46.9% of the US population) had a state law in effect as of July 5, 2010, that required workplaces, restaurants, and bars to be 100% smoke-fvree.[35] ■

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Contributors

M.S. Dove and T. Land contributed to the design, statistical analysis, and writing of the article. D.W. Dockery contributed to the design and performed critical revisions of the article. E.M. Sullivan reviewed and categorized the smoke-free air laws. M.A. Mittleman, J. Schwartz, and L. Keithly also contributed to the design of the study. All authors helped to conceptualize ideas, interpret findings, and review drafts of the article.

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Human Participant Protection

No protocol approval was needed for this study because data were obtained from secondary sources.

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