Rapid publication

Reduction in asthma-related emergency department visits after implementation of a smoke-free law

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Background: Secondhand tobacco smoke increases the risk for the development and increasing severity of asthma among adults and children. Reducing exposure to secondhand smoke decreases symptomatic exacerbations among patients with asthma. Emergency department (ED) visits for asthma were assessed before and after the implementation of smoke-free legislation in Lexington-Fayette County, Ky.

Objective: To evaluate the effects of a smoke-free law on the rate of ED visits for asthma.

Methods: The study included ED visits for asthma from 4 hospitals in Lexington-Fayette County, Ky. Age-adjusted rates of asthma ED visits were determined. Poisson regression analysis of ED visits from January 1, 2001, to December 31, 2006 compared the ED visit rates between prelaw and postlaw, adjusting for seasonality, secular trends over time, and differences among demographic subgroups. The actual rates were graphed with the Poisson curve showing the rates predicted by the model. A second prediction curve was generated to show the projected rates in the postlaw period if the law had not been implemented.

Results: Adjusting for seasonality, secular trends, and demographic characteristics, ED visits for asthma declined 22% from prelaw to postlaw ($P < .0001$; 95% CI, 14% to 29%). The rate of decline was 24% in adults age 20 years and older ($P < .0001$), whereas the decrease among children 19 years or younger was 18% ($P = .01$).

Conclusion: Although this study did not establish causation, the smoke-free law was associated with fewer asthma ED visits among both children and adults, with a more significant decline among adults. (J Allergy Clin Immunol 2008;122:537-41.)

Key words: *Asthma, asthma triggers, asthma exacerbation, secondhand tobacco smoke, environmental tobacco smoke, smoke-free legislation, asthma health outcomes*

Secondhand tobacco smoke (SHS) is a well documented environmental trigger for the development of asthma symptoms among adults[1-3] and children in the United States.[4,5] SHS contains respiratory irritants that increase bronchial hyperactivity and airway inflammation with resultant symptomatic exacerbation for individuals with pre-existing asthma.[6] There is a strong association between the length of SHS exposure time and self-reported number of consultations with doctors, medication use, and missed work days.[7] Eliminating SHS exposure decreases asthma severity, emergency department (ED) visits, and hospitalizations among nonsmoking adults with asthma.[8]

More than 20 million adults[9] and 9 million children[10] in the United States have been diagnosed with asthma. The adult self-reported asthma prevalence in Kentucky for 2004 was slightly higher than the national average (8.3% vs 8.1%).[11] Kentucky residents may be disproportionately affected by asthma exacerbations because of increased smoking rates and fewer smoke-free homes. Kentucky leads the nation in adult smoking, 28.6% compared with 20.2% nationwide.[12] Similarly, Kentucky led the nation in home exposure to SHS in 2003, with only 53.4% reporting smoke-free homes compared with 72.2% nationwide.[13]

Although 12 US states and 277 communities have adopted laws requiring all workplaces, restaurants, and bars to be smoke-free, many states and municipalities have been slow to protect all workers from exposure to SHS.[14] Lexington-Fayette Urban County Government's smoke-free law, the first in Kentucky, prohibits smoking in most public places including, but not limited to, restaurants, bars, bowling alleys, bingo halls, convenience stores, laundromats, and other businesses open to the public.

This study evaluated the effects of Lexington's smoke-free law on the rate of ED visits for asthma. Asthma events were measured 40 months before and 32 months after enforcement of the smoke-free public places law in Lexington-Fayette County, Ky, on April 27, 2004. It was hypothesized that if SHS was eliminated from public places, the incidence of ED visits for asthma would decrease.

METHODS

All 5 Lexington-Fayette County hospitals were asked to provide de-identified records of ED cases from 2001 to 2006, including primary and secondary discharge diagnoses (International Classification of Diseases, Ninth

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Abbreviations used
ED: Emergency department
RR: Relative risk
SHS: Secondhand tobacco smoke

Revision codes), date of service, sex, age, and county of residence. Patients treated in Fayette but who lived outside the county were excluded from the analysis. Complete data from 1 hospital were not available for this study because their data collection software had changed in 2002 and it was not fully implemented until more than a year into the study period. Asthma ED discharges from this hospital accounted for 13% of the total cases from 2002 to 2006. Data from this hospital were not included in the analysis. The study was approved by the University of Kentucky and the other hospital Institutional Review Boards.

Selection of cases

Primary and secondary diagnoses were reviewed to determine whether the event qualified for inclusion in the study. Selection of cases was limited to those with either a primary or secondary discharge diagnosis of asthma (International Classification of Diseases, Ninth Revision code 493). Discharge diagnosis was chosen as the criterion for inclusion because it is a more accurate reflection of the true condition than the diagnosis at admission. Asthma cases from January 1, 2001, to December 31, 2006, were included in the study: 40 months prelaw and 32 months postlaw. Because the percent increase in cases from 2001 to 2002 was higher than between any other consecutive pair of years, a sensitivity analysis was conducted that excluded data from 2001 to discern whether the difference in rates between the prelaw and postlaw periods was significant for this shorter time frame; for the sensitivity analysis, the prelaw and postlaw periods were 28 and 32 months, respectively.

Statistical methods

Descriptive statistics were used to summarize patient populations before and after the smoke-free law. Yearly totals of cases in Lexington-Fayette County were combined with corresponding population estimates to obtain crude annual rates.[15] These rates were age-adjusted and standardized to the 2000 US Census estimates.

Monthly rates for asthma ED visits over the 6-year study period were modeled using Poisson regression, with the negative binomial distribution specified to allow for overdispersion or underdispersion. The initial regression model included the fixed effects of law status (prelaw vs postlaw), sex, age (with 11 categories corresponding to census data cohorts), and the 2-way and 3-way interactions of these effects. The log of the estimated population size was used as an offset variable in the model, with population estimates specific to the year, sex, and age category of the cases. The model also contained an indicator for time (month of event) to assess secular trends unrelated to law implementation; this variable was treated as continuous in the model, with January 2001 numbered as 1 and December 2006 numbered as 72. The first-order and second-order harmonics were included in the models to account for seasonal variation in rates. The formulas for the *j*th-order harmonic terms are as follows:

$$S_j = \sin(2 * j * m * \pi/12) \text{ and } C_j = \cos(2 * j * m * \pi/12),$$

where j denotes the order of the harmonic and takes values of 1 or 2, and m denotes the month of the year and ranges from 1 (January) to 12 (December).

Interaction terms not significant in the initial model were sequentially removed for ease of interpretation with little change in model fit. Goodness-of-fit of the models was determined by using the deviance statistic.

In addition to Poisson regression, a time series analysis was conducted based on a first-order autoregressive model. Consistent with the findings of Kuhn et al,[16] who evaluated these 2 strategies for quantifying time trends of relatively rare outcomes (eg, asthma ED visits), we found no appreciable difference in the level of significance of any of the predictors between these 2 methods. The Poisson regression results are reported here because this method estimates the relative risk of an event postlaw compared with prelaw, adjusting for demographic, time-trend, and seasonal variables in the model. In addition, separate regression models were considered for children (age 0-19 years) and adults (age 20 years and above). Actual rates per 100,000 population, weighted by sex and age distribution, were plotted with the predicted rates estimated from the model. Data analyses and graphing were conducted by using SAS for Windows, v. 9.1 (SAS Institute, 2002-03); an α level of .05 was used throughout.

RESULTS

From January 2001 through December 2006, there were a total of 14,839 ED visits for asthma events: 7763 prelaw (ie, through April 2004) and 7076 postlaw. The prelaw and postlaw cohorts were very similar in demographic characteristics. The prelaw cohort had an average age of 29.5 years (SD = 21.6) and was 63% female, compared with an average age of 29.7 (SD = 21.3) and 63% female postlaw. Thirty-six percent of prelaw cases were younger than 20 years, equivalent to the percentage of pediatric cases postlaw. As shown in Table I, there is a pattern of increasing frequency of ED visits for asthma over time, which is also reflected in the age-adjusted rates. This steady increase was interrupted in 2004, the year when the law was implemented, with an age-adjusted rate for all cases that was decreased from the previous year. This change in trend is evident in the pediatric and adult subsets as well. The final Poisson regression model based on all cases fit the data well; the ratio of the deviance statistic to the degrees of freedom was 1.1, close to the null value of 1. Significant predictors of the rate of ED visits for asthma in the Poisson regression included the law status indicator (pre vs post), age, sex, and the age by sex interaction; the time-trend variable and 3 of the 4 first-order and second-order harmonic terms were also significant (Table II). Adjusting for these demographic, trend, and seasonal factors, the relative risk (RR) of an asthma ED visit postlaw versus prelaw was 0.78 ($\chi^2 = 26.6$; $P < .0001$); the 95% CI for the RR was 0.71 to 0.86. When children (age 0-19 years) and adults (age 20 years and above) were considered separately, both models fit the data well (with the ratio of deviance to degrees of freedom for the 2 models equal to 1.1 and 1.06, respectively). The decline in the pediatric cohort was significant (RR = 0.82; 95% CI for RR, 0.71-0.96; $\chi^2 = 6.3$; $P = .01$), and the degree of decline in adult cases was even more striking (RR = 0.76; 95% CI for RR, 0.69-0.84; $\chi^2 = 26.3$; $P < .0001$). There was a 22% decline in ED visits for asthma for all ages combined, and an 18% decline among children and a 24% decline in adults.

Consistent with the age-adjusted rates presented in Table I and the significant decline in RR postlaw, Fig 1 illustrates that for the children and adult cases combined, although there was an increasing trend in ED visits for asthma over the 6-year period, there was a drop in rates after the law. The prevalence of ED visits for asthma postlaw was lower than the prevalence projected by the model if the smoke-free law had not been implemented. The models for the pediatric and adult subsets are displayed separately in the Online Repository (see this article's Fig E1 and Fig E2 at www.jacionline.org); both figures illustrate a decline in asthma ED rates after the law, with the larger difference observed for the adult subset.

For the sensitivity analysis, cases from 2001 were omitted. The model based on all cases from 2002 to 2006 had a significant decrease in ED rate between prelaw and postlaw (RR = 0.90;

TABLE I. Size of the at-risk population, number and rate* of asthma ED visits per year, 2001-2006

	All cases			Pediatric (age 0-19 y)			Adult (age 20 y and above)		
Year	At-risk population	No. of asthma ED visits	Rate*	At-risk population	No. of asthma ED visits	Rate*	At-risk population	No. of asthma ED visits	Rate*
2001	262,186	1680	650.5	65,486	583	250.7	196,700	1097	399.8
2002	262,652	2574	996.4	65,314	917	397.9	197,338	1657	598.5
2003	265,479	2659	1015.4	65,715	957	410.5	199,764	1702	604.9
2004	266,443	2514	951.6	65,779	902	380.8	200,664	1612	570.8
2005	268,076	2594	982.9	66,058	1011	427.5	202,018	1583	555.4
2006	270,935	2818	1058.4	66,764	952	400.3	204,171	1866	658.1

*Age-adjusted rate per 100,000 at-risk population, adjusted to the 2000 US Census.

TABLE II. Poisson regression models for the full sample and adult and child subsets, 2001-2006

	All cases			Pediatric (age 0-19 y)			Adult (age 20 y and above)		
Variable	RR	95% CI for RR	χ^2 (*P* value)	RR	95% CI for RR	χ^2 (*P* value)	RR	95% CI for RR	χ^2 (*P* value)
Month	1.01	1.01-1.01	76.7 (<.0001)	1.01	1.01-1.01	26.8 (<.0001)	1.01	1.01-1.01	67.8 (<.0001)
Age	0.96	0.95-0.97	41.2 (<.0001)	0.84	0.80-0.88	53.8 (<.0001)	0.93	0.91-0.94	67.2 (<.0001)
Male	2.08	1.88-2.30	179.1 (<.0001)	2.39	2.02-2.84	91.2 (<.0001)	0.48	0.37-0.61	33.2 (<.0001)
Age*Male	0.77	0.75-0.78	578.2 (<.0001)	0.75	0.71-0.81	65.7 (<.0001)	0.95	0.92-0.99	6.8 (.009)
Harmonics									
S_1	1.02	0.99-1.06	1.7 (.2)	1.06	1.00-1.12	4.3 (.04)	0.99	0.95-1.03	0.4 (.5)
C_1	1.06	1.03-1.10	12.3 (.0005)	1.18	1.11-1.25	32.8 (<.0001)	1.00	0.97-1.04	< 0.1 (.9)
S_2	0.91	0.88-0.94	29.9 (<.0001)	0.87	0.82-0.92	25.9 (<.0001)	0.93	0.90-0.97	14.1 (.0002)
C_2	0.94	0.90-0.97	14.9 (.0001)	0.88	0.83-0.92	22.9 (<.0001)	0.97	0.94-1.01	2.5 (.1)
Postlaw indictor	0.78	0.71-0.86	26.6 (<.0001)	0.82	0.71-0.96	6.3 (.01)	0.76	0.69-0.84	26.3 (<.0001)

95% CI, 0.81-0.99; $\chi^2 = 4.6$; $P = .03$; see this article's Table E1 in the Online Repository at www.jacionline.org). The model for pediatric cases from 2002 to 2006 did not have a significant pre/post difference (RR = 0.99; 95% CI, 0.85-1.16; $\chi^2 < 0.1$; $P = .9$), whereas the adult model estimated the RR for this effect to be 0.85 (95% CI, 0.76-0.95; $\chi^2 = 8.1$; $P = .004$). The rate of decline in the adult subset was 15%, whereas the decrease between prelaw and postlaw was 10% when all cases were considered. Although these are more modest decreases than in the analysis of cases from the full study period (2001-2006), the findings underscore the association between the smoke-free law and a decline in asthma ED visits for this more conservative analysis.

DISCUSSION

During the 32 months after implementation of a smoke-free law in Lexington-Fayette County, Ky, there was a significant 22% decline in ED visits for asthma after controlling for seasonality, secular trends, and the demographics of the at-risk population. The rate of decline was greater among adults age 20 years and older compared with pediatric cases 19 years and younger. This age disparity was even more striking in the sensitivity analysis; the rate of decline was significant in adults, but there was no effect among children. Given that children are primarily exposed to SHS in the home[17] and adults are exposed both at home and in the workplace,[18] it is not unexpected that the smoke-free law would be more likely to protect adults than children.

This is the first study to report an association between smoke-free laws and ED visits for asthma. Because Lexington's ordinance covers all public places including restaurants and bars but not all places of employment, the reported decline may be an underestimate of the effect of comprehensive smoke-free laws on asthma.

The overall upward trend in ED visits for asthma during this period is consistent with the national data showing an increase from 1.6 million ED visits for asthma in 2001 to 1.7 million ED visits for asthma in 2005.[19] From 1992 to 2004, the estimated rate of ED visits for asthma in the United States increased from 57.3 to 63.4 per 10,000 population.[20] In the Southern Region, the estimated rate of ED visits for asthma increased from 7.7 in 2001 to 9.1 per 100 persons with asthma in 2004.[20] The current asthma prevalence rate for Lexington-Fayette County, Ky, increased during the study period (6.4% in 2001 to 7.1% in 2006).[21] Given that asthma prevalence increased during this time, we would expect that ED visits would increase. Our findings show that the smoke-free law interrupted the steady increase in ED visits for those with asthma.

It is well known that there is a causal relationship between outdoor air pollution and morbidity and mortality for asthma.[22] In an indoor air quality study of Lexington hospitality venues, there was a 91% decline in fine particle air pollution after Lexington's smoke-free law went into effect.[23] Given that there is a positive association between outdoor air pollution and ED visits for asthma[24] among both children[25,26] and adults,[26,27] it is not surprising that there were fewer asthma ED visits in light of improved indoor air quality after Lexington's smoke-free law. Further study is needed to investigate the interactions among outdoor air pollution, smoke-free legislation, and asthma prevalence and health care outcomes.

Studies show positive health effects of smoke-free laws using a variety of health indicators. Within 3 months after Lexington's smoke-free law took effect, there was a 56% decline in hair nicotine, a biomarker for SHS exposure, and a significant improvement in reported respiratory symptoms among restaurant and bar workers.[28] In a population-based study of New York residents, nonsmoking adults showed a 47.4% decrease in saliva cotinine after a comprehensive statewide smoke-free law.[29]

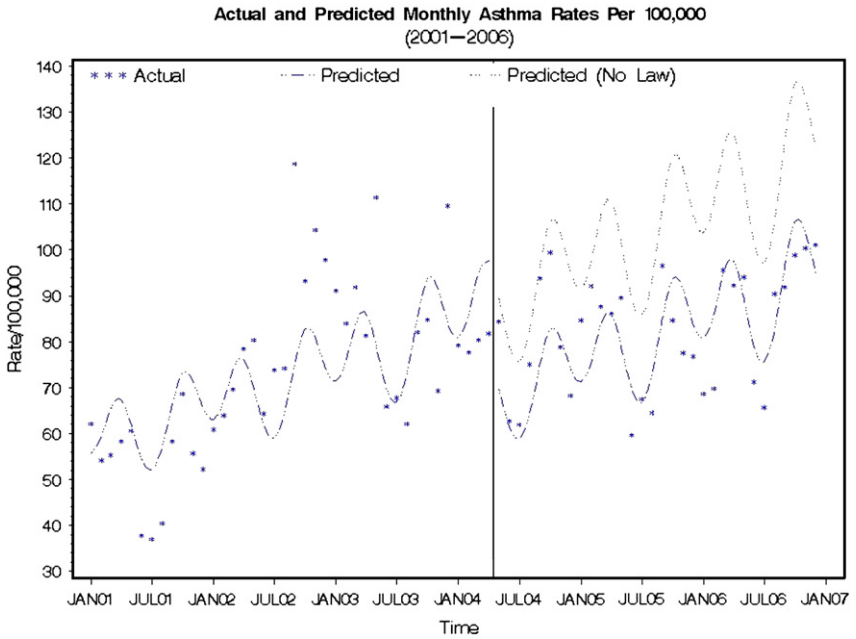

FIG 1. Actual and predicted monthly rates of asthma ED admissions per 100,000 population in Lexington-Fayette County, 2001-2006; the vertical line indicates the division between prelaw and postlaw periods. The Poisson regression model used to determine the predicted rates demonstrated a 19% decrease in ED visits for asthma after the community smoke-free law. The graph contains a second postlaw curve, the projected rate of ED visits had the law not been implemented.

Multiple studies have linked smoke-free workplace and public places legislation to significant declines in hospitalizations for acute myocardial infarction in the general population.[30-34]

Limitations

There was the potential for underestimation of asthma cases, given the migration of workers both in and out of Lexington. Health outcomes of those who work in the county but who live elsewhere were not investigated because place of work was unavailable. Likewise, Lexington-Fayette County residents who work elsewhere may have visited an ED in a noncounty hospital during work hours and were not included in the analysis. In addition, we may have underestimated the asthma cases because of potential differences in coding by physicians or hospitals. Another limitation is that we did not have a matched control group, and we were not able to monitor trends in a population without a smoke-free law. Although we included a control for changes in case frequency over time because of secular trends, we were not able to measure changes in these trends specifically, including rate of asthma diagnosis and changes in treatment regimen. We cannot infer causation; rather, we can say that there was an association between Lexington's smoke-free law and ED visits for asthma. Although an association was observed, there are other explanations that could account for the observations. This study presumes that exposure to SHS declined after implementation of the law, but an additional limitation is that actual exposure of individuals was not measured.

Conclusion

There was a 22% decline in ED visits after Lexington's smoke-free public places law when controlling for seasonality, secular trends, and the demographics of the at-risk population. Because there is no risk-free level of SHS,[17] eliminating SHS exposure is essential to respiratory health. The National Heart, Lung, and Blood Institute Expert Panel on the diagnosis and management of asthma recently updated guidelines for the management of asthma, identifying SHS as a major trigger in asthma morbidity and recommending that clinicians advise their patients who have asthma not to smoke and to avoid involuntary exposure to SHS.[35] SHS is difficult to avoid unless legislation is passed to create smoke-free workplaces and public places in all communities. This study is the first to find an association between smoke-free laws and reductions in ED visits for asthma in the general population. More research is needed to explore further the relationship between smoke-free legislation and health care use related to asthma.

We thank the 4 Lexington-Fayette County hospital systems for providing the database for this study.

Clinical implications: Eliminating SHS, an environmental risk factor for asthma exacerbation, by enacting smoke-free legislation can decrease ED visits for asthma.

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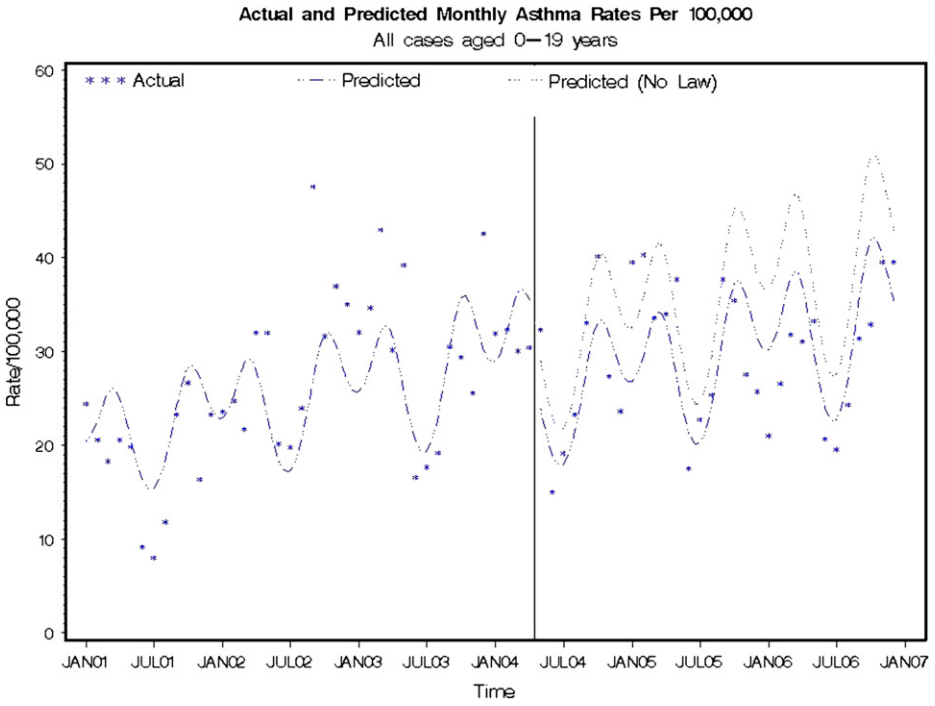

FIG E1. Actual and predicted monthly rates of pediatric asthma ED admissions per 100,000 population in Lexington-Fayette County, 2001 to 2006. The *vertical line* indicates the division between prelaw and postlaw periods. The Poisson regression model used to determine the predicted rates demonstrated an 18% decrease in ED visits for asthma among children after the community smoke-free law. The *graph* contains a second postlaw curve, the projected rate of ED visits had the law not been implemented.

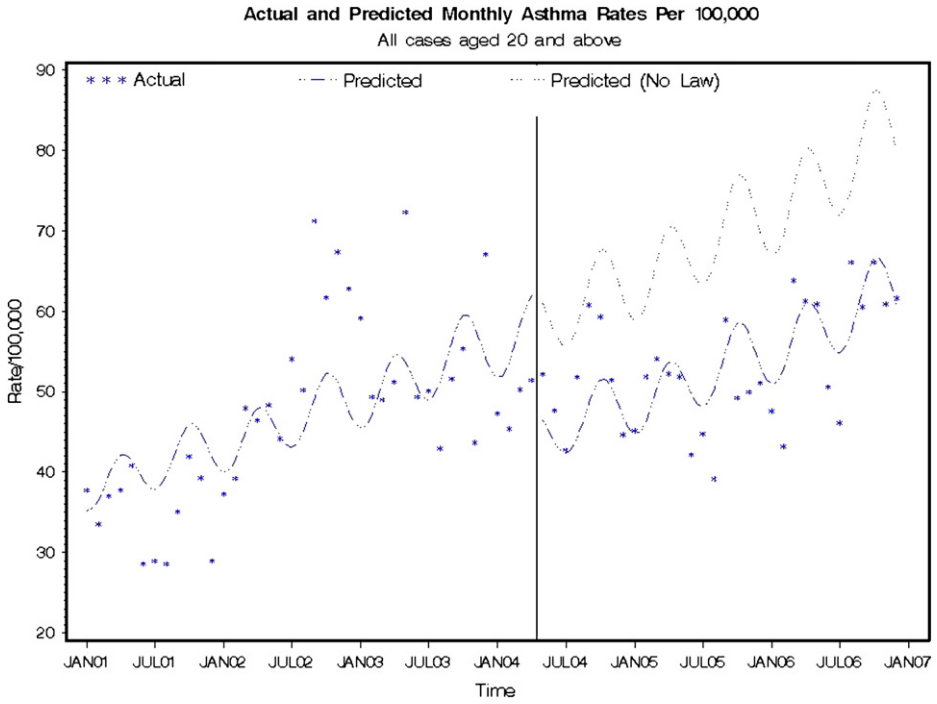

FIG E2. Actual and predicted monthly rates of adult asthma ED admissions per 100,000 population in Lexington-Fayette County, 2001 to 2006. The *vertical line* indicates the division between prelaw and postlaw periods. The Poisson regression model used to determine the predicted rates demonstrated a 24% decrease in ED visits for asthma among adults after the community smoke-free law. The *graph* contains a second postlaw curve, the projected rate of ED visits had the law not been implemented.

TABLE E1. Poisson regression models for the full sample and adult and child subsets, 2002 to 2006

	All cases			Pediatric (age 0-19 y)			Adult (age 20 y and above)		
Variable	**RR**	**95% CI for RR**	**χ^2 (*P* value)**	**RR**	**95% CI for RR**	**χ^2 (*P* value)**	**RR**	**95% CI for RR**	**χ^2 (*P* value)**
Month	1.00	1.00-1.01	6.6 (.01)	1.00	1.00-1.01	0.2 (.7)	1.01	1.00-1.01	10.8 (.001)
Age	0.96	0.95-0.97	41.6 (<.0001)	0.85	0.81-0.89	39.9 (<.0001)	0.92	0.90-0.94	70.3 (<.0001)
Male	2.09	1.88-2.33	166.3 (<.0001)	2.43	2.04-2.89	88.0 (<.0001)	0.48	0.37-0.62	30.2 (<.0001)
Age*Male	0.77	0.76-0.79	512.9 (<.0001)	0.75	0.70-0.81	61.7 (<.0001)	0.95	0.92-0.99	5.8 (.02)
Harmonics									
S_1	1.00	0.97-1.04	< 0.1 (.9)	1.04	0.99-1.10	2.3 (.1)	0.97	0.93-1.00	3.1 (.08)
C_1	1.06	1.03-1.10	11.6 (.0007)	1.17	1.11-1.24	28.6 (<.0001)	1.01	0.97-1.05	0.2 (.7)
S_2	0.91	0.87-0.94	29.8 (<.0001)	0.86	0.82-0.91	26.4 (<.0001)	0.93	0.89-0.96	13.9 (.0002)
C_2	0.94	0.91-0.97	11.5 (.0007)	0.88	0.84-0.93	18.7 (<.0001)	0.98	0.94-1.01	1.6 (.2)
Postlaw indictor	0.90	0.81-0.99	4.6 (.03)	0.99	0.85-1.16	< 0.1 (0.9)	0.85	0.76-0.95	8.1 (.004)