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RESEARCH ARTICLE

Smoke-Free Policies and 30-Day Readmission Rates for Chronic Obstructive Pulmonary Disease

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Introduction: Previous evidence has shown that smoke-free policies reduce hospital admissions due to respiratory causes, but the impact on 30-day readmission has not been determined. As 25 states in the U.S. have not adopted comprehensive smoke-free legislation, it is likely that patients return to an environment that increases risk of a secondary event. The aim of this study is to investigate the impact of smoke-free policies on 30-day readmission rates for adults aged ≥65 years following hospitalization for chronic obstructive pulmonary disease in the U.S.

Methods: Data from the U.S. Tobacco Control Laws Database, Centers for Medicare and Medicaid Services Hospital Readmissions Reduction Program, American Hospital Association, Area Health Resource File, and U.S. Census Bureau Current Population Survey were merged at the county level for years 2013−2016 and analyzed in 2018. Hierarchical Poisson regression models were utilized to calculate incidence rate ratios to determine the impact of full, partial, and no smoke-free policies on 30-day readmission rates after chronic obstructive pulmonary disease hospitalization.

Results: Multivariable analysis adjusting for both county and hospital characteristics revealed that the presence of full (incidence rate ratio=0.81, 95% CI=0.76, 0.88) and partial (incidence rate ratio=0.87, 95% CI=0.81, 0.92) smoke-free policies were associated with fewer 30-day readmissions for chronic obstructive pulmonary disease−related hospitalizations when compared with counties with no smoke-free policy.

Conclusions: The implementation of smoke-free policies is an effective measure for reducing 30-day readmissions following hospitalization due to chronic obstructive pulmonary disease, with stronger policies resulting in decreased risk. Efforts to reduce chronic obstructive pulmonary disease−related 30-day readmissions should include the implementation of smoke-free policies.
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INTRODUCTION

Comprehensive smoke-free legislation, which consists of any policy that prohibits smoking 100% indoors with no exceptions, has been shown to decrease rates of respiratory morbidity[1−7] and mortality,[8] but 25 states in the U.S. have not adopted these policies as of January 2, 2019.[9] Partial smoke-free legislation, which allows exemptions for certain indoor areas, is common in the U.S., but yields mixed findings regarding health outcomes.[3,10,11] However, it is clear that secondhand smoke causes negative physiologic changes to occur in the body within minutes to hours of exposure.[12−14] For example, carbon monoxide in secondhand smoke binds to red blood cells in place of oxygen, thereby increasing risk of adverse cardiovascular

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and cardiopulmonary events.[12,13,15–18] Even 1 hour of exposure to secondhand smoke at levels expected in a restaurant or bar can result in the elevation of inflammatory markers that lasts for hours after lung function has returned to normal.[14] Additionally, there is increasing evidence that thirdhand smoke, which is composed of residual surface pollutants from tobacco smoke, is associated with negative physiologic impacts.[19,20]

Chronic obstructive pulmonary disease (COPD) is a leading cause of death in the U.S.[21] and accounts for approximately $30 billion of direct healthcare costs.[22] Several studies have investigated factors involved in exacerbations of COPD that result in hospitalizations and readmissions, most of which have investigated individual-level factors such as age,[23–25] sex,[26] race,[26] SES,[23,25,27,28] and comorbidities.[24,25] However, population-level factors such as public health policy have not been explored in association with COPD readmissions. Although individual-level factors are important in predicting exacerbations of COPD, the presence of smoke-free policies may also be important.[29]

Several studies have been conducted to ascertain the impacts of smoke-free policies on respiratory-related hospital admissions,[2,6,30–33] but the impact on readmissions has not been determined. This association is important to determine not only for policymakers and public health practitioners, but also for hospitals for whom unplanned, 30-day readmissions are used as a measure of quality.[34,35] When patients residing in a state or county without smoke-free policy coverage are discharged back into the community, it is likely that they return to an environment that increases the risk of a secondary event. The aim of this study is to investigate the impact of smoke-free policies on 30-day readmission rates following COPD hospitalization in the U.S.

METHODS

Study Population

Tobacco control laws data were provided by the American Nonsmokers' Rights Foundation U.S. Tobacco Control Laws Database, which contained 11,514 smoke-free policies for 5,074 U.S. municipalities, 1,788 counties, all 50 states, and the District of Columbia since 1936.[36] The 2017 Centers for Medicare and Medicaid Services Hospital Readmission Reduction Program data set reported unplanned risk-adjusted 30-day hospital readmission rates due to COPD for inpatient discharges from July 1, 2013 to June 30, 2016. The 2017 American Hospital Association annual survey collected structural, procedural, and outcome information on approximately 6,000 hospitals from 2013 to 2016. The 2018 Area Health Resource File reported multiyear data collected from >50 sources and provided county-level health resources including socioeconomic indicators.[37] The 2013–2016 Current Population Survey was administered by the U.S. Census Bureau to household adults aged ≥18 years and provided 1- and 5-year population estimates annually. Data sets were merged using county Federal Information Processing Standards.

Measures

To examine associations between county-level smoke-free policies and average hospital COPD readmission rates, unplanned risk-adjusted 30-day readmission rates following COPD inpatient discharges were used as the outcome variable.[34] Readmission rates for COPD were risk-adjusted for patient characteristics including medical history, comorbidities, age, and sex and were standardized for each hospital through the use of hierarchical linear modeling to estimate an expected and predicted 30-day readmission for COPD. This ratio was multiplied by the unadjusted overall readmission rate.[38,39] As the unit of analysis was at the county level, the average 30-day readmission rate following COPD inpatient discharge from hospitals within a county was estimated.[40]

The key independent variable was constructed based on comprehensive smoke-free legislation covering public and private workplaces, restaurants, and bars through June 30, 2016, defined as a policy that prohibits smoking 100% indoors without any exceptions.[36] State and county smoke-free laws were used to create a record for each county law in effect as of May 1, 2013, which was 60 days before the study period, to account for the potential of businesses to use the 60-day delayed effective date allowable for U.S. policy implementation.[41] For this study, the District of Columbia was included as a county. An ordinal smoke-free policy variable was operationalized at 3 levels: full coverage, partial coverage, and no coverage. A county was categorized as having full coverage if there was a 100% smoke-free policy for workplaces, restaurants, and bars. A county was categorized as having partial coverage if there was a 100% smoke-free policy in 1 or 2 of the 3 places. A county was categorized as no coverage if there was not a 100% smoke-free policy in any of the 3 places (workplaces, restaurants, bars).

To minimize bias that might arise from differing county characteristics, variables previously identified as important for respiratory outcomes were included. Prior studies have illustrated that both racial and ethnic minority populations experience gaps in health access and quality outcomes.[42] Therefore, for the study period (2013–2016), an average entropy index score examining the amount of diversity and population evenness within a county[43] was estimated by calculating the sum of the log proportions of the 6 racial/ethnic groups defined in the U.S.: African Americans, American Indians or Alaskan Natives, Asians, Native Hawaiians or other Pacific Islanders, Hispanics, and white non-Hispanics. The closer the score to 1.79, the more diverse (i.e., even) the population.[44] The average median age of the population was included as a continuous variable because age is associated with increased respiratory-related chronic conditions and years impacted by smoke-free policies. The average percentage of the population living in rural areas, female and aged ≥65 years, and in poverty was included; additionally, the average percentage of the population aged ≥65 years with ≥4 years of college was calculated as an indicator of disparity in disease burden.[45]

To control for hospital-level factors within the study period, statistical models were adjusted for hospital size, ownership, teaching status, system status, tobacco services offered, proportion of Medicare and Medicaid discharges, and market competition. Hospital size was reported as the average number of staffed inpatient beds and is a predictor of hospital quality performance and resources.[46] Hospital

ownership was measured as the average percentage of not-for-profit hospitals as an indicator of a county's health service delivery quality performance.[47] Teaching hospital status was reported as a categorical variable (teaching and non-teaching hospital) and operationalized as a continuous variable of total number of teaching hospitals within the county to serve as an indicator of hospital safety performance and readmission rates.[48] System status was operationalized as the total number of hospitals that are part of a system, which has been shown to determine resource availability and market power.[49] Total number of tobacco services offered by hospitals in the form of smoking-cessation programs was used to identify availability of community-based intervention to reduce smoking rates.[50,51] Both average Medicare and Medicaid percentages were measured as the proportion of a hospital's total Medicare or Medicaid visits and total inpatient admissions, and were used to assess hospital financial well-being.[52] Finally, market competition for hospitals in each county was measured using the Herfindahl–Hirschman Index (HHI), an estimate of the ratio of a hospital's total inpatient days and county total inpatient days. An HHI of 1 indicates a monopolistic market.[53,54]

Statistical Analysis

The analysis was constrained to include counties that had at least 1 hospital present. A power calculation was conducted to ensure sufficient sample sizes in the Poisson regression analyses to determine the difference in readmission rate for the 3 levels of smoke-free policy at a significance level of 0.05.[55] Means and SDs were used to summarize the merged data. Variance inflation factors and variance–covariance matrix correlation assessment yielded low values, indicating that multicollinearity was not problematic. Hierarchical Poisson regression models were deployed to calculate incidence rate ratios (IRRs) for the ordinal smoke-free law variable to account for counties nesting within states. The total population covered by the policy was accounted for by incorporating it as a measure of the extent of exposure.

Three variations of the model were used. The first included county sociodemographic characteristics. The second included hospital characteristics. The third and full model included both county and hospital characteristics. Regression models were summarized using the adjusted R^2 to ensure that overfitting did not occur, and statistical significance was assessed at an α level of 0.05. Two types of approaches were used for model assessment: Akaike information criterion and Bayesian information criterion tests. All data were analyzed in 2018 using Stata, version 14.2.

RESULTS

There were 1,788 counties included in the analyses. Of these, 384 (21%) had no smoke-free policy coverage, 569 (32%) had partial coverage, and 835 (47%) had full coverage (Table 1). On average, the no smoke-free policy

Table 1. Descriptive Summary of Study Variables by Smoke-Free Policy Category

	No coverage		Partial coverage		Full coverage	
County characteristics	**Mean (SD)**	***n***	**Mean (SD)**	***n***	**Mean (SD)**	***n***
Average number of counties per state	64.00 (46.38)	384	52.70 (31.24)	569	51.07 (23.57)	835
Total number of hospital beds	291.80 (725.97)	287	464.06 (970.81)	505	463.72 (1,208.56)	763
Total population covered by smoke policy	533,958.70 (1,780,083)	384	59,898.04 (168,057.00)	569	61,037.10 (308,953.70)	835
Percentage of county designated as rural	53.98 (29.32)	355	44.43 (29.34)	565	46.02 (29.66)	831
Average percent poverty	18.40 (6.00)	355	15.89 (6.01)	566	14.88 (5.76)	830
Average median age, years	38.91 (4.44)	287	40.00 (5.41)	505	40.50 (5.01)	763
Average entropy index	0.75 (0.28)	285	0.69 (0.29)	502	0.62 (0.30)	758
Chronic obstructive pulmonary disease 30-day readmission	17.03 (6.40)	287	16.51 (6.29)	505	15.94 (6.76)	763
Average Medicaid percentage	0.16 (0.13)	287	0.18 (0.11)	505	0.21 (0.14)	763
Average Medicare percentage	0.55 (0.16)	287	0.53 (0.15)	505	0.50 (0.17)	763
Average Herfindahl–Hirschman index	0.55 (0.29)	199	0.45 (0.30)	402	0.39 (0.31)	561
Total number of hospitals part of a system	1.04 (1.62)	287	1.65 (2.47)	505	1.62 (3.28)	763
Total number of teaching hospitals	0.61 (1.49)	287	1.07 (2.16)	505	1.19 (2.83)	763
Percentage of not-for-profit hospitals	41.14 (46.41)	287	58.13 (44.20)	505	68.99 (41.53)	763
Total number of hospital tobacco services	0.76 (1.24)	287	1.24 (1.79)	505	1.20 (1.87)	763
Average percentage of population ≥65 years with ≤4 years college	16.62 (7.60)	355	20.80 (10.01)	566	20.52 (8.74)	831
Average percentage of female ≥65 years	55.44 (2.47)	355	55.26 (2.44)	566	55.15 (2.56)	831

group had the lowest number of total beds (291.80), lowest population covered by smoke-free policies (533,958.70), lowest median age (38.90 years), lowest proportion of hospital discharges covered by Medicaid (16%), lowest number of teaching hospitals (0.61), lowest percentage of not-for-profit hospitals (41.14%), lowest average number of hospitals providing tobacco services (0.076), and the lowest percentage of the population aged ≥65 years with ≥4 years in college (16.62%). Additionally, the no smoke-free policy group also had the largest average percentage of the county designated rural (53.98%), highest average percentage of the population in poverty (18.40%), highest average entropy (0.75) indicating greater diversity, highest COPD 30-day readmission rate (17.03), highest percentage of hospital discharges covered by Medicare (55%), and highest average HHI (0.55) indicating lower competition in the county.

Multivariable analyses (Table 2) revealed that the presence of a smoke-free policy was associated with reductions in 30-day readmissions for COPD in all 3 models. In Model 1, which assessed county demographic characteristics and policy coverage, full smoke-free coverage was associated with a reduction in the IRR of 0.82 (95% CI=0.77, 0.86), whereas partial smoke-free coverage was associated with a 0.80 reduction in the IRR (95% CI=0.76, 0.85), compared with counties with no smoke-free policy. Counties with a greater percentage of the population aged ≥65 years with ≥4 years in college (IRR=0.95, 95% CI=0.05, 0.95), a greater percentage female and aged ≥65 years (IRR=0.94, 95% CI=0.94, 0.95), and a higher entropy score (IRR=0.36, 95% CI=0.34, 0.39) were associated with having fewer 30-day COPD readmissions. Additionally, percentage of the county designated as rural (IRR=1.02, 95% CI=1.02, 1.02) and average median age (IRR=1.03, 95% CI=1.03, 1.04) were positively associated with an increased risk for 30-day COPD readmissions.

Model 2 assessed smoke-free policies and hospital characteristics. As in Model 1, full and partial coverage policies were associated with reduced incidence rates for 30-day COPD readmissions of 0.67 (95% CI=0.63, 0.72) and 0.79 (95% CI=0.24, 0.84), respectively. Counties with a greater number of Medicaid and Medicare discharges were associated with a 5.79 (95% CI=4.69, 7.14) and 4.83 (95% CI=4.10, 5.67) increase in the incidence rate of 30-day COPD readmissions, respectively. Additionally, both a higher HHI (IRR=2.79, 95% CI=2.62, 2.96) and a greater number of hospitals part of a system (IRR=1.11, 95% CI=1.09, 1.13) were associated with increased risk of

Table 2. Hierarchical Poisson Regressions of COPD; County Characteristics, Hospital Characteristics, and All Characteristics

Characteristics	Model 1 (*n*=1,545) IRR (95% CI)	Model 2 (*n*=1,162) IRR (95% CI)	Model 3 (*n*=1,160) IRR (95% CI)
Smoke-free policy (ref: no coverage)			
Partial coverage	**0.80*** (0.76, 0.85)**	**0.79*** (0.74, 0.84)**	**0.87*** (0.81, 0.92)**
Full coverage	**0.82*** (0.77, 0.86)**	**0.67*** (0.63, 0.72)**	**0.81*** (0.76, 0.88)**
County characteristics			
Percentage of county designated as rural	**1.02*** (1.02, 1.02)**		**1.02*** (1.01, 1.02)**
Average percentage of population ≥65 years with ≥4 years college	**0.95*** (0.95, 0.95)**		**0.98*** (0.97, 0.98)**
Average percentage of females ≥65 years	**0.94*** (0.94, 0.95)**		**0.97*** (0.96, 0.98)**
Average percent poverty	0.99 (0.99, 1.00)		**1.03*** (1.02, 1.03)**
Average median age	**1.03*** (1.03, 1.04)**		**1.04*** (1.03, 1.04)**
Average entropy index	**0.36*** (0.34, 0.39)**		**0.73*** (0.67, 0.79)**
Hospital characteristics			
Average number of hospital beds		**0.99*** (0.99, 0.99)**	**0.99*** (0.99, 0.99)**
Average Medicaid percentage		**5.79*** (4.69, 7.14)**	**0.78* (0.63, 0.95)**
Average Medicare percentage		**4.82*** (4.10, 5.67)**	0.90 (0.77, 1.06)
Average Herfindahl–Hirschman index		**2.783*** (2.61, 2.96)**	**1.72*** (1.62, 1.84)**
Total number of hospitals part of a system		**1.11*** (1.09, 1.13)**	**1.07*** (1.06, 1.09)**
Total number of teaching hospitals		**0.87*** (0.86, 0.89)**	**0.89*** (0.88, 0.91)**
Average percentage of not-for-profit hospitals		**0.99*** (0.99, 0.99)**	1.00 (0.99, 1.00)
Total number of hospital tobacco services		1.00 (0.99, 1.02)	**1.05*** (1.04, 1.07)**
Model fit statistics			
AIC	28,900.49	22,317.39	18,385.23
BIC	28,953.92	22,378.09	18,476.24

Note: IRR exponentiated coefficients; 95% CI in parentheses. Boldface indicates statistical significance (*p<0.05; **p<0.01; ***p<0.001).
AIC, Akaike information criterion; BIC, Bayesian information criterion; COPD, chronic obstructive pulmonary disease; IRR, incidence rate ratio.

readmissions. Counties with a greater number of teaching hospitals were associated with decreased incidence of readmissions (IRR=0.87, 95% CI=0.86, 0.89).

Model 3 considered both county-level demographic and hospital characteristics. In the full model, smoke-free policies were associated with a decrease in 30-day readmissions following COPD hospitalization, with full coverage being associated with a 0.81 (95% CI=0.76, 0.87) IRR reduction and partial coverage being associated with a 0.87 (95% CI=0.81, 0.92) reduction compared with counties with no smoke-free policies. County demographic and hospital characteristics associated with increased 30-day readmissions included increased percentage of county designated as rural (IRR=1.02, 95% CI=1.01, 1.02), increased percentage in poverty (IRR=1.03, 95% CI=1.02, 1.03), increased median age (IRR=1.04, 95% CI=1.03, 1.04), increased HHI (IRR=1.72, 95% CI=1.62, 1.84), and increased number of hospitals part of a system (IRR=1.07, 95% CI=1.06, 1.09). Characteristics associated with decreased 30-day readmissions included increased percentage of the population aged ≥65 years with ≥4 years in college (IRR=0.98, 95% CI=0.97, 0.98), increased entropy index (IRR=0.73, 95% CI=0.67, 0.79), increased number of Medicaid discharges (IRR=0.78, 95% CI=0.63, 0.95), and increased number of teaching hospitals (IRR=0.89, 95% CI=0.87, 0.91).

DISCUSSION

After adjusting for both county characteristics and hospital characteristics, 30-day readmissions following hospitalization for COPD were 19% less likely for patients living in counties with a full coverage smoke-free policy and were 13% less likely for patients living in counties with partial smoke-free policy coverage when compared to patients living in counties with no smoke-free policy. This study added a unique adjustment by using the average entropy index score for each county as a measure of diversity and population evenness. Counties with a greater entropy index were mostly located on the coasts and within states that had implemented smoke-free policies. Additionally, a more even racial distribution of the population within an area likely promotes better health outcomes, whereas a less even distribution and segregation of the population is associated with worse outcomes.[56] The no coverage counties in this study had similar characteristics associated with increased readmission rates for COPD, including lack of tobacco control services,[57] rural location,[25] and higher Medicaid/Medicare coverage.[58] This at-risk population may need additional support from policymakers in advocating for smoke-free policies.

The finding that greater numbers of teaching hospitals per county are associated with decreases in readmissions is consistent with evidence on readmissions due to stroke,[59] aneurysm,[60] and COPD.[61] Several prior studies analyzing COPD rates as the primary outcome saw an overall decrease in hospital admissions associated with smoke-free policies.[6,25,57,58] Similar methods to this study were used in a 2017 Spanish study that observed a strong decline in COPD-related hospital admissions following a partial, and a later comprehensive, smoke-free policy.[1]

Although, to the authors' knowledge, this is the first study to examine the impacts of smoke-free policies on 30-day readmissions following COPD hospitalizations, these findings are consistent with that of a meta-analysis demonstrating that smoke-free policies result in significantly lower rates of primary hospital admissions due to respiratory diseases (RR=0.760; 95% CI=0.682, 0.846) with more comprehensive policies resulting in stronger risk reductions.[3] In addition, the main findings are consistent with those of a previous study in Kentucky, which observed that individuals who lived in an area with comprehensive smoke-free law coverage were 22% less likely to be hospitalized for COPD than individuals who lived in an area with no smoke-free law.

Based on the evidence provided through this and previous studies, it is evident that comprehensive smoke-free policies provide better COPD-associated outcomes. Policymakers should consider the strength of smoke-free policies in effect for areas in which at-risk populations for COPD admissions and readmission reside. Implementation of comprehensive smoke-free policies may help improve not only the rate of COPD readmissions, but also may help decrease poor health outcomes associated with secondhand smoke.

This study is, to the authors' knowledge, the first to explore the impacts of smoke-free policies on 30-day COPD readmissions. The data sources were comprehensive and included in-depth, county-level smoke-free policy information as well as multiple county- and hospital-level indicators, thereby allowing adjustment for multiple potential confounders and increasing rigor of statistical estimates. The employment of hierarchical Poisson regression models also accounted for the multilevel structure of the data, specifically counties nesting within states.

Limitations

The timing of each smoke-free policy for every county in the U.S. was difficult to account for in this study. The smoke-free policy variable was operationalized in a cross-sectional manner, wherein policies were categorized based upon current status at the beginning of the study period. As such, it was not possible to determine duration effects of smoke-free policies. However, no county or state implemented a 100% smoke-free policy in any of the 3 places within the 60-day window or during the study period.

Additionally, the data sources did not provide information on individual smoking status or on the availability of smoking-cessation services at the county level, and it is possible that some patients who were active or former smokers may have reinitiated smoking after a short period of cessation during first hospitalization. Although active smoking is an established risk factor for COPD-related hospitalizations, it has not been identified as a strong risk determinant for readmissions following COPD hospitalization, thereby reinforcing the implication of secondhand smoke as a risk factor for COPD-related readmissions.[25,58] Unfortunately, with such a large study conducted on a national scale, individual exposure to secondhand smoke could not be estimated. Thus, the total population covered by the policy was accounted for by including it as a measure of the extent of exposure.

Counties with no smoke-free policy coverage differed from partial and full coverage counties in several potential confounders such as SES and educational attainment. Additionally, the no coverage counties had the largest percentage of geographic area designated as rural, and agricultural work has been shown to be independently associated with COPD.[62–65] Lastly, because 30-day readmission rates are overall hospital rates, it was not possible to estimate individual patients' month of admission. As such, seasonality could not be assessed as a potential confounder.

CONCLUSIONS

The implementation of smoke-free policies is an effective measure for reducing 30-day readmissions following hospitalization because of COPD. After adjusting for multiple county and hospital characteristics, these findings indicated that the stronger the level of the smoke-free policy, the greater the reductions in readmissions following COPD hospitalization. Efforts to reduce COPD-related 30-day readmissions should include prioritizing the adoption and implementation of comprehensive smoke-free policies.

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