Journal of Toxicology and Environmental Health, Part A, 70: 2064–2070, 2007

ISSN: 1528-7394 print / 1087-2620 online
DOI: 10.1080/15287390701601236

Hospitalization Patterns Associated with Appalachian Coal Mining

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The goal of this study was to test whether the volume of coal mining was related to population hospitalization risk for diseases postulated to be sensitive or insensitive to coal mining by-products. The study was a retrospective analysis of 2001 adult hospitalization data (*n*= 93,952) for West Virginia, Kentucky, and Pennsylvania, merged with county-level coal production figures. Hospitalization data were obtained from the Health Care Utilization Project National Inpatient Sample. Diagnoses postulated to be sensitive to coal mining by-product exposure were contrasted with diagnoses postulated to be insensitive to exposure. Data were analyzed using hierarchical nonlinear models, controlling for patient age, gender, insurance, comorbidities, hospital teaching status, county poverty, and county social capital. Controlling for covariates, the volume of coal mining was significantly related to hospitalization risk for two conditions postulated to be sensitive to exposure: hypertension and chronic obstructive pulmonary disease (COPD). The odds for a COPD hospitalization increased 1% for each 1462 tons of coal, and the odds for a hypertension hospitalization increased 1% for each 1873 tons of coal. Other conditions were not related to mining volume. Exposure to particulates or other pollutants generated by coal mining activities may be linked to increased risk of COPD and hypertension hospitalizations. Limitations in the data likely result in an underestimate of associations.

Over the past several years, coal has become more competitive as a source of power and fuel because of (1) energy security concerns, (2) an increase in the cost of oil and gas, (3) evidence for the near-term occurrence of peak global oil production, and (4) concerns about nuclear power. The United States has 27% of all known coal reserves (Folger, 2006). The U.S. Department of Energy estimates that 153 new coal-fired power plants will come on line by 2030 (Klara & Shuster, 2007). Increases in coal mining in response to these pressures pose potential adverse health risks for persons who live in the vicinity of the mining activities.

Anecdotal evidence on the negative health effects of living near coal mining sites in Appalachia is widespread. Residents reported serious health consequences they experience from living in the coalfields (Goodell, 2006). Water quality studies documented contaminated well water in West Virginia and Kentucky communities consistent with coal slurry toxins (McSpirit & Dieckmann, 2003; Stout & Papillo, 2004). However, quantitative research on the relationship between residential proximity to coal mining sites and health consequences is rare; research conducted has been limited to studies in Great Britain and to a narrow range of respiratory illnesses. These studies found elevated levels of particulate matter (PM) (Pless-Mulloli et al., 2000a) and increased symptoms of respiratory morbidity (Pless-Mulloli et al., 2000b; Brabin et al., 1994; Temple & Sykes, 1992) associated with residential proximity to coal mining sites. Contaminated dust from coal washing activities is a significant local phenomenon (Ghose & Banerjee, 1995). The harmful exposures faced by coal miners—diesel particulates, dust, chemicals, fuels, and elemental toxins (Scott et al., 2004)—may be found in less concentrated form but for larger populations of individuals living near the mining sites.

Previous research has established an association between hospitalization patterns and daily measures of air pollution in metropolitan areas (Simpson et al., 2005; Wellenius et al.,

Received 27 April 2007; accepted 13 June 2007.
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2006; Barnett et al., 2006; Yang et al., 2004; 2007). These hospitalizations, for cardiovascular disease, asthma, and other respiratory diseases, are thought to result from exacerbations of existing illnesses from PM. A similar phenomenon may exist for residents exposed to pollution from coal mining activities. However, previous research on residential proximity to coal mining (Pless-Mulloli et al., 2000b; Brabin et al., 1994; Temple & Sykes, 1992) has not examined hospitalization patterns. Therefore, the current study examines the relationship between hospitalization patterns and coal mining production among residents of three Appalachian states in the United States: Kentucky, Pennsylvania, and West Virginia.

METHODS

Design

The study is a retrospective analysis of 2001 person-level hospitalization data from Kentucky, Pennsylvania, and West Virginia, merged with 2001 county-level data on tons of coal mined and other county-level data.

Sample and Data Sources

Hospital data are taken from the Health Care Utilization Project (HCUP) National Inpatient Sample (NIS) of short-stay general hospitals for 2001. These data are coordinated through the Agency for Healthcare Research and Quality (AHRQ), and are available as de-identified discharge abstracts for research purposes. The NIS data represents approximately a 20% probability sample of all hospitals in participating states. For the current study, adults 19 yr and older with all diagnoses were included, except for maternal cases and transfers from other hospitals, resulting in a sample of 93,952 hospitalizations from 90 sampled hospitals. Maternal cases were excluded so as not to confound denominators in the hospitalization rates with normal labor and delivery, instead limiting the denominator to forms of illness or injury. Not every state participates in the NIS, and among those that do, only some provide the county identifier field. Among major coal-producing Appalachian states, counties were identified in the NIS data by Kentucky, Pennsylvania, and West Virginia, and thus are included in this study.

Coal production figures for 2001 were obtained from the Energy Information Administration (Annual Coal Report, 2002). The figures included the tons of coal mined in thousands from each county in both underground and surface mines. There were 73 counties represented in this database (including counties that mined no coal) with matching records in the NIS sample.

Other county indicators included percent of population in poverty from U.S. Census data, and a measure of county production of social capital, standardized to a mean of 0 across all counties in the nation (Rupasingha et al., 2006). Social capital has been shown in other research to be an important correlate of population health (Lochner et al., 2003).

Variables

NIS variables used for analysis include patient age (in years, categorized as 19–44, 45–64, 65–74, 75+), gender, payer (insured or uninsured), diagnoses, and hospital teaching status (teaching hospitals are academic health centers that conduct patient care, research, and medical education, and that tend to serve most complex cases). The Federal Information Processing Standards (FIPS) code was used to identify the county location of the hospital. The dependent variable was found from the diagnosis given in the primary diagnostic field. Diagnoses were grouped into those postulated to be "coal exposure sensitive" and "coal exposure insensitive." The list of candidates for sensitive conditions is preliminary and based on previous health risks reported in the literature for coal miners, findings established from exposure to air particulate pollution, or evidence for kidney or cardiovascular disease related to exposure to toxins found in association with coal mining (Wellenius et al., 2006; Barnett et al., 2006; Navas-Acien et al., 2004, 2005; Nishijo et al., 2006; Coggon & Taylor, 1998; Sarnat et al., 2006; Noonan et al., 2002). Where to place lung cancer is unclear; risk of lung cancer was linked to diesel particulate matter (Monforton, 2006), but other research found no elevated risk for lung cancer among miners after controlling for smoking behavior (Montes et al., 2004); for this study lung cancer was tentatively positioned in the "sensitive" column. A list of postulated coal exposure-sensitive and -insensitive conditions is provided in Table 1. The list of potential insensitive conditions is not intended to be final or exhaustive but to offer a sample of "control" conditions that are expected to be unrelated to coal mining exposure. Each diagnosis is thus a dichotomous variable, and the question becomes whether an exposure-sensitive diagnosis is significantly higher in coal mining areas as a proportion of total hospitalizations, whereas

TABLE 1
List of Potential Candidates for Coal-Sensitive and Coal-Insensitive Conditions, With Corresponding Diagnostic Codes

Coal-sensitive		Coal-insensitive	
Category	ICD-9 codes	Category	ICD-9 codes
Lung cancer	162	Diabetes	250
COPD	490–492, 494–496	Musculoskeletal and connective	710–739
Hypertension	401–405	Organic psychoses	290–294
Kidney disease	580–589		
Congestive heart failure	428		
Ischemic heart disease	410–413		
Asthma	493		

exposure-insensitive conditions should not differ as a function of coal mining intensity.

Other NIS variables are used as covariates. These include age, gender, uninsurance, hospital teaching status, and comorbidities. Comorbidities are measured in two ways: first, by the count of nonmissing secondary diagnosis fields ranging potentially from 0 to 14, and second, by a Charlson index (Charlson et al., 1987) calculated for each case based on diagnostic codes reported by Romano et al. (1993) and scored 0 to 3 to indicate increasing severity of comorbidities.

Coal production was not normally distributed across counties. Because more than half of the counties produced no coal, a square-root transformation was preferred over a log transformation. The coal production variable was transformed by taking the square root of tons of coal measured in thousands. The coal production variable was linked to the hospital records at the county level.

Analysis

After descriptive analyses, inferential analyses determined whether hospitalizations for "exposure-sensitive" and "exposure-insensitive" conditions were significantly elevated as a function of coal production, accounting for other variables likely to correlate with health indicators. The analysis was done at the person level using HLM 6.03 multilevel Bernoulli modeling for the dichotomous presence of the dependent variable diagnosis. The square root of county-level coal production was included as a level 2 predictor. Level 1 (person-level) covariates included gender, age, uninsurance status, hospital teaching status, comorbidity count, and Charlson index. Level 2 (county-level) covariates included social capital and poverty rates. The intercept effect was treated as a random variable but other predictors were treated as fixed. Results are reported for final population estimates with robust standard errors. Significant coal effects are identified based on odds ratios greater than 1 at the 95% confidence interval.

Additional analyses examined gender differences to confirm that coal effects were not limited to men, who may be current or former miners, and to examine scatterplots between observed and expected level 2 residuals to confirm adequate model fit.

RESULTS

Table 2 summarizes descriptive characteristics of study variables. The average age of the sample was about 67, and about 56% of patients were female. The most common diagnoses among those coded for analysis were congestive heart failure, ischemic heart disease, chronic obstructive pulmonary disease (COPD), and diabetes.

Table 3 summarizes hierarchical model results. Greater coal mining was positively related to more hospitalizations for two postulated coal-sensitive conditions, hypertension and COPD.

TABLE 2
Descriptive Summary of Study Variables

Variable	Mean or %	St. deviation	Minimum–maximum
Person-level (n = 93,952)			
Mean age	66.9	14.3	19–105
Mean comorbidity count	4.12	2.10	0–9
Mean Charlson index	0.41	0.65	0–3
Percent female	55.7		
Percent uninsured	1.57		
Percent teaching hospital admissions	33.2		
Percent with primary diagnosis of:			
COPD	3.33		
Asthma	0.92		
Hypertension	1.39		
Kidney disease	1.09		
Congestive heart failure	9.61		
Ischemic heart disease	4.57		
Diabetes	7.62		
Lung cancer	0.40		
Organic psychoses	0.49		
Musculoskeletal and connective disorders	3.83		
County-level (n = 73)			
Tons of coal×1000	1957.70	6643.16	0–44303
Square root (tons of coal×1000)	20.94	39.25	0–210.48
Percent population below poverty	15.22	6.69	4.8–37.7
Social capital index	-0.17	0.42	−1.14–0.50

It was not significant for other conditions, including the potential insensitive conditions. There was a significant *negative* relationship between coal production and hospitalization for lung cancer and kidney disease.

The odds ratios are expressed relative to the square root of coal in thousands of tons. Transforming the odds ratios back to the original metric results in the odds of a COPD hospitalization increasing 1% for each 1462 tons of coal, and the odds for a hypertension hospitalization increasing 1% for each 1873 tons of coal.

The possibility that the results may reflect current or former miners who live in the area, rather than a general population effect, may be dismissed through an examination of gender effects. Almost all coal miners are men. Results for the significant COPD model show no gender effect, and results for the significant hypertension model show a higher risk for women.

TABLE 3
Hierarchical Model Results, Coal Production Effects Controlling for Person and County Covariates

Independent variables	COPD Odds ratio	COPD 95% Confidence interval	LUNG CANCER Odds ratio	LUNG CANCER 95% Confidence interval
Coal production	1.003	1.001–1.006	0.997	0.993–1.000
County poverty rate	1.017	0.987–1.048	1.010	0.966–1.056
Social capital	–0.467	0.416–0.945	1.205	0.641–2.266
Age	1.154	1.098–1.213	1.216	1.076–1.374
Female	0.979	0.870–1.102	0.681	0.545–0.851
Teaching status	0.789	0.584–1.065	1.775	0.931–03.382
Comorbidity count	0.918	0.901–0.935	0.878	0.823–0.936
Charlson Index	0.664	0.600–0.735	3.602	3.220–4.029
Uninsured	0.681	0.464–0.999	0.238	0.079–0.714
	Hypertension		Diabetes	
Coal production	1.003	1.001–1.005	0.998	0.994–1.001
County poverty rate	0.992	0.957–1.027	1.045	0.980–1.113
Social capital	0.701	0.413–1.190	1.504	0.614–3.685
Age	1.086	1.033–1.141	0.605	0.582–0.629
Female	1.218	1.061–1.399	0.899	0.849–0.951
Teaching status	1.236	0.707–2.158	0.978	0.833–1.147
Comorbidity count	0.977	0.944–1.012	0.906	0.885–0.928
Charlson Index	0.913	0.847–0.985	0.983	0.936–1.033
Uninsured	1.739	0.976–3.098	1.808	1.559–2.098
	Kidney disease		Organic psychoses	
Coal production	0.997	0.994–0.999	0.998	0.994–1.001
County poverty rate	1.000	0.972–1.030	1.003	0.965–1.043
Social capital	0.639	0.408–1.000	1.812	0.833–3.941
Age	1.077	1.010–1.149	1.251	0.986–1.589
Female	1.005	0.908–1.112	0.563	0.465–0.681
Teaching status	1.269	0.975–1.635	0.509	0.151–1.717
Comorbidity count	1.441	1.352–1.536	1.025	0.918–1.145
Charlson Index	0.909	0.807–1.024	0.702	0.590–0.835
Uninsured	0.465	0.192–1.130	1.039	0.452–2.392
	Ischemic heart disease		Musculoskeletal	
Coal production	0.998	0.995–1.002	1.002	1.000–1.004
County poverty rate	1.002	0.973–1.032	0.985	0.957–1.014
Social capital	0.957	0.643–1.428	2.629	1.653–4.181
Age	1.108	1.066–1.151	0.987	0.938–1.039
Female	0.733	0.697–0.771	1.177	1.062–1.305
Teaching status	0.999	0.741–1.347	1.044	0.798–1.365
Comorbidity count	1.037	1.005–1.069	0.869	0.837–0.903
Charlson Index	0.809	0.771–0.849	0.741	0.680–0.809
Uninsured	1.494	1.077–2.073	0.463	0.294–0.729

(*Continued*)

TABLE 3
(*Continued*)

	COPD		LUNG CANCER	
Independent variables	Odds ratio	95% Confidence interval	Odds ratio	95% Confidence interval
	Asthma		Congestive heart failure	
Coal production	0.999	0.996–1.003	1.000	0.999–1.001
County poverty rate	0.981	0.941–1.022	1.009	0.986–1.033
Social capital	0.898	0.554–1.453	0.823	0.604–1.121
Age	0.598	0.549–0.651	1.324	1.280–1.368
Female	2.536	2.010–3.199	1.028	0.963–1.098
Teaching status	0.855	0.617–1.183	0.757	0.591–0.970
Comorbidity count	0.898	0.875–0.923	1.119	1.096–1.143
Charlson Index	0.448	0.388–0.517	1.049	1.004–1.095
Uninsured	0.690	0.468–1.018	0.885	0.567–1.381

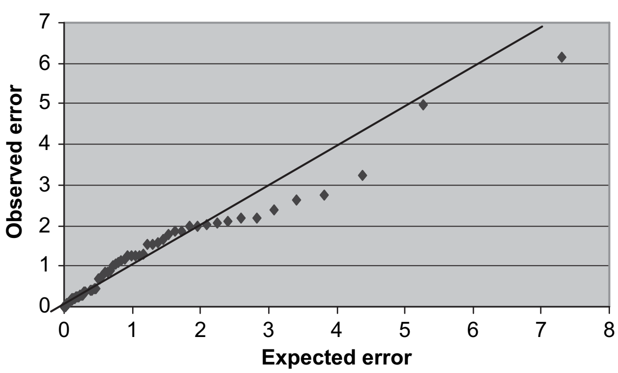

FIG. 1. Scatterplot showing observed and expected level 2 residuals for hypertension model.

The scatterplot of observed to expected model residuals was examined to determine whether the level 2 errors in the model were randomly distributed. Figure 1 shows that observed and expected errors are closely related. This figure is for the hypertension model, but the COPD model showed similar results. The correlation between observed and expected error in Figure 1 was .98.

DISCUSSION

This is the first study to show that hospitalizations for COPD and hypertension are significantly elevated as a function of Appalachian coal production at the county level. The risk increases significantly as the volume of coal mining rises. The effects might be a result of exposure to PM associated with mining activities such as coal extraction and washing (Ghose & Banerjee, 1995), exposure to diesel particulate matter from operation of engines at mining sites (Monforton, 2006), or some interactive combination thereof.

Effects were not found for other conditions that were hypothesized to be sensitive to coal exposure, including kidney disease, lung cancer, and forms of heart disease. This might be due to exposure effects that are too weak to exert negative impacts on residents, limitations in the precision of the hospitalization data (discussed in more detail later), or time lags between exposure and illness. Exposure effects were not found for any of the potential insensitive conditions. These lists of sensitive and insensitive conditions are only a starting point for refined classifications as knowledge on this topic progresses.

Limitations of this study include the ecological design, which prohibits drawing a definitive causal link between the hospitalization event and coal mining activities. Adjustments were made for a set of demographic and county indicators, but it is possible that other unmeasured variables may contribute to poorer health in a way that is confounded with coal mining. Smoking and obesity, in particular, were not measured. However, the reverse finding for lung cancer suggests that coal production and smoking patterns are not confounded. Air pollution levels from industrial sources were also not measured, although power plants tend to be located in population centers and along major rivers, whereas primary coal mining locations often occur in separate, more rural areas. The weather patterns associated with a particular season might also affect both illness and volume of mining (i.e., a cold winter increases susceptibility to illness and increases economic demand for coal); this issue may be addressed in future research by examining effects for longer time intervals. The use of the proportional hospitalization indicator, like a proportional mortality ratio, has limitations (Miettinen & Wang, 1981; Decoufle et al., 1980), such as its dependence on the relative frequency of coal-sensitive to -insensitive conditions in the population.

The data are also limited by the geographic crudeness of the county measure: Some persons may live in a coal mining county but some distance from the mining activities, while others live across county lines but closer to mining sites. Future research would be improved by obtaining a more refined geographic match between residence and coal mining activities; possibilities include secondary census tract data (e.g., Vassilev et al., 2001), or primary data collection studies with geographic information system (GIS) indicators. Unfortunately, the coal production figures for this study were not available on those smaller scales.

A significant limitation of the hospitalization data is that the county identified the location of the hospital, not necessarily the location where the patient resided. Persons who were transferred from other hospitals were excluded from analysis, but this is not a complete solution. To the extent that people move from one area to another for hospital care, this introduces error into the measurement. This error appear to be random rather than systematic, making detection of effects more difficult but not creating bias in the direction of effects. To make an argument for biased results due to patient mobility, one would have to argue that people differentially move from non-coal-mining areas to coal-mining areas for hospital care, for only COPD and hypertension and not for other conditions, and that this occurs relative to the intensity of mining. This particular pattern of movement seems unlikely. To the extent that error is random, with some patients moving into and out of coal producing areas for care, coal mining effects will be underestimated.

Another limitation of hospitalization data is that they are an indicator that is influenced by various other factors, including the quality of the ambulatory care system, and payer or geographic variation in diagnostic practices, in ways that could not be measured. COPD and hypertension in many cases are instances of ambulatory care-sensitive conditions. If the quality of outpatient care for these conditions is systematically poorer in coal mining areas, this might result in more frequent hospitalizations, but again, one would have to argue this poor quality phenomenon selectively for COPD and hypertension, when other ambulatory care-sensitive conditions, such as diabetes, showed no relationship to coal mining. Local diagnostic practice variations, such as distinctions between adult asthma and COPD, may also introduce error into estimates, as may differences due to type of payer.

The teaching status of the hospital was a variable that sometimes affected admission patterns. Teaching status likely interacts with mobility patterns, where patients with complex or serious illnesses are more likely to travel from their area of residence to a teaching hospital for specialty care. To the extent that teaching hospitals are located in urban areas where coal mining does not take place, this pattern may obscure possible coal-related effects. Lung cancer and kidney disease represent serious, complex illnesses, and hospitalization for these conditions was marginally higher as a function of teaching status ($p < .10$), which may help to account for their nonsignificant links to coal mining. Hypertension and COPD, on the other hand, were related to less severe comorbidities and unrelated to hospital teaching status, suggesting that these conditions are more likely to be treated at local hospitals near the patient's residence.

Despite the data limitations, which may be expected to dilute the magnitude of effects, effects were found for two health problems that are consistent with an exposure hypothesis. The inhalation of PM is associated with hypertension (Ibald-Mulli et al., 2001; Brook, 2005; Urch et al., 2005; Krewski et al., 2005) and COPD (Brabin et al., 1994; Coggon & Taylor, 1998) among miners and residents and in lab conditions. Individuals with hypertension show increased association between systemic inflammation and ambient PM2.5 (particulate matter with a mass mean aerodynamic diameter ≤2.5 μm) (Dubowsky et al., 2006). The current study may be detecting the acute effects from residential exposure to PM at a certain time, or a chronic exposure effect that accumulates over time into increased risk of hospitalization. Other research has found that long-term exposure to ambient air pollution is related to higher incidence and mortality rates from cardiopulmonary disease and lung cancer (Miller et al., 2007; Krewski et al., 2005). Additional research using more refined methods will be necessary to isolate the nature and magnitude of the exposure effect. Future research may employ primary data collection efforts in targeted communities distal and proximal to coal mining activities to collect data on physiological measures and disease incidence for residents in these communities. Future studies need to clearly identify specific processes and pollutants that exert pathologic effects on local populations.

CONCLUSIONS

The health consequences of exposure to mining activities reflect only a portion of the entire coal production and consumption cycle. Coal mining poses occupational hazards to miners (Scott et al., 2004), its burning contributes to air pollution and subsequent health hazards (Wellenius et al., 2006), and carbon emissions contribute to climate change with potential global health risks, including infectious epidemics, disruptions in the food chain, increased asthma prevalence, lung damage from ozone, and health consequences of floods and droughts (Patz et al., 2005; Bernard et al., 2001; Epstein, 2005). The health risks from residential proximity to mining present an additional negative consequence that results from reliance on this energy source.

If exposure effects are supported by further research, economic analyses of coal's contribution to domestic productivity may need to be revised to take into account the lost productivity and medical care costs linked to residential proximity to mining. Calculation of pollution levels in geographic areas may be developed to account for both the production and consumption of carbon-based energy. Implementation of national or state environmental and public health policies may be indicated to protect nearby citizens from mining by-product exposure.

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