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Mortality from heart, respiratory, and kidney disease in coal mining areas of Appalachia

Michael Hendryx

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Abstract

Purpose The purpose of this study was to test whether population mortality rates from heart, respiratory and kidney disease were higher as a function of levels of Appalachian coal mining after control for other disease risk factors.

Methods The study investigated county-level, age-adjusted mortality rates for the years 2000–2004 for heart, respiratory and kidney disease in relation to tons of coal mined. Four groups of counties were compared: Appalachian counties with more than 4 million tons of coal mined from 2000 to 2004; Appalachian counties with mining at less than 4 million tons, non-Appalachian counties with coal mining, and other non-coal mining counties across the nation. Forms of chronic illness were contrasted with acute illness. Poisson regression models were analyzed separately for male and female mortality rates. Covariates included percent male population, college and high school education rates, poverty rates, race/ethnicity rates, primary care physician supply, rural-urban status, smoking rates and a Southern regional variable.

Results For both males and females, mortality rates in Appalachian counties with the highest level of coal mining were significantly higher relative to non-mining areas for chronic heart, respiratory and kidney disease, but were not higher for acute forms of illness. Higher rates of acute heart and respiratory mortality were found for non-Appalachian coal mining counties.

Conclusions Higher chronic heart, respiratory and kidney disease mortality in coal mining areas may partially reflect environmental exposure to particulate matter or toxic agents present in coal and released in its mining and processing. Differences between Appalachian and non-Appalachian areas may reflect different mining practices, population demographics, or mortality coding variability.

Keywords Heart disease · Respiratory disease · Kidney disease · Mortality · Coal mining · Appalachia

M. Hendryx (✉)
Institute for Health Policy Research,
Department of Community Medicine,
West Virginia University, One Medical Center Drive,
PO Box 9190, Morgantown, WV 26506, USA
e-mail: mhendryx@hsc.wvu.edu

Introduction

Exposure to environmental pollutants increases risks for heart, respiratory and kidney disease. For example, low levels of environmental lead exposure accelerate progressive renal insufficiency in patients with chronic kidney disease (Lin et al. 2006), and environmental lead increases cardiovascular mortality in the general population (Menke et al. 2006). Mercury from industrial activity has been linked to kidney disease mortality (Hodgson et al. 2007). Arsenic in drinking water increases mortality from cardiovascular and kidney disease (Meliker et al. 2007). Cadmium exposure increases risk of renal dysfunction (Nishijo et al. 2006; Noonan et al. 2002). In addition to toxic agents, particulate matter (PM) from fossil fuel combustion increases risks for cardiovascular and respiratory disease morbidity and mortality (Barnett et al. 2006; Miller et al. 2007; Pope et al. 2002; Sarnat et al. 2006; Wellenius et al. 2006).

Appalachia is the mountainous, largely rural area in the eastern United States consisting of 417 counties and independent cities in 13 states. Previous research has identified that rates of cardiovascular, respiratory, and total mortality are higher in Appalachia compared to the rest of the country

(Barnett et al. 1998, 2000; Cakmak et al. 2006; Halverson et al. 2004). Furthermore, heart disease mortality in Appalachia is higher in rural areas of the region compared to metropolitan areas (Barnett et al. 1998). Comparative rates for kidney disease have not been reported. Higher mortality rates in Appalachia are believed to result from higher smoking rates, poor dietary and exercise habits, and the correlates of poor socioeconomic conditions characteristic of the region such as limited access to health care.

However, another potential impact on the health of the population may originate from the environmental impacts of Appalachian coal mining. Coal mining constitutes a major industrial activity for eight Appalachian states (Alabama, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia and West Virginia), where 390 million tons were mined in 2004 (Freme 2005). Residents of Appalachian coal mining communities report exposure to contaminated air and water from coal mining activities and express concerns for resulting illnesses (Goodell 2006), but empirical evidence on community health risks from coal mining activities is limited (Brabin et al. 1994; Hendryx and Ahern 2007; Hendryx et al. 2007, 2008; Higgins et al. 1969; Temple and Sykes 1992). Coal contains toxic impurities including zinc, cadmium, lead, mercury, arsenic and many others (WVGES 2007), and the mining and cleaning of coal at local processing sites creates large quantities of ambient particulate matter and contaminated water (Ghose and Banerjee 1995; Ghose and Majee 2000; Orem 2007; Stout and Papillo 2004). Not only toxic impurities, but the particulate matter from coal itself released into air or water during mining or processing may be a health hazard. Shiber (2005) reports elevated arsenic levels in drinking water sources in coal mining areas of central Appalachia, and McAuley and Kozar (2006) report that groundwater from sampled domestic wells near reclaimed surface coal mines, compared to wells in unmined areas, has higher levels of mine-drainage constituents including aluminum, iron, manganese, and others. It should be noted, however, that the chemical composition of coal slurry is largely undefined (Orem 2007) and that arsenic and other elements may result from various sources and may be present even in areas where no coal mining takes place. The objective of the current study was to determine whether heart, lung and kidney disease mortality rates in Appalachia are attributable to smoking, poverty, education, and other demographics, or whether there is an additional effect linked to residence in coal mining areas.

Methods

This study investigated mortality rates for the years 2000–2004 for heart, respiratory and kidney disease. The study is an analysis of anonymous, secondary data sources and met university Internal Review Board standards for an exemption from human subjects review.

Mortality data were obtained from the Centers for Disease Control and Prevention (CDC). These data measure county-level mortality rates per 100,000 population, age-adjusted using the 2000 US standard population (CDC 2007b). Disease categories were based on ICD-113 Groups provided by the CDC, which were cross-walked to ICD-10 Codes (The ICD-10 codes are provided in the parentheses in the Table 1 footnote). Diseases were grouped into acute or chronic conditions as shown in Table 1. Specifically excluded were codes for “pneumoconioses and chemical effects”, and “pneumonitis due to solids and liquids”, as these are established as occupational hazards related to coal mining, rather than potential population risks. Also excluded were several low-incidence categories for “other” or “unspecified” forms of disease or other low-incidence mortality causes. Because most coal miners are men, mortality rates were investigated separately for males and females to test the hypothesis that mining effects would be present for both sexes; support of this hypothesis suggests that results are not attributable to occupational exposure.

Coal production data were obtained from the energy information administration (Freme 2001, 2002, 2003, 2004, 2005). Production was measured as tons of coal mined in the county in both surface and underground mines. Analyses divided Appalachian coal mining into two levels: up to 4 million tons, and more than 4 million tons for the years 2000–2004. The choice of 4 million tons divided the number of coal mining counties approximately in half. Because the focus in this paper is on Appalachian coal mining, 97 non-Appalachian counties where coal mining took place were included as a separate category.

Covariates were taken from the 2005 Area Resource File (ARF 2006), CDC BRFSS smoking rate data (CDC 2007a), and the Appalachian Regional Commission (ARC 2007). Selection of covariates was based on previously identified risk factors or correlates of heart, respiratory or kidney disease (Barnett and Halverson 2001; Barnett et al. 2000; Hoffman and Paradise 2007; Iverson et al. 2005; Jones-Burton et al. 2007; Kunitz and Pesis-Katz 2005; Mannino and Buist 2007; Murray et al. 2005; Ziembroski and Brieding 2006). Covariates included percent male population, college and high school education rates, poverty rates, race/ethnicity rates, health uninsurance rates, physician supply, rural–urban continuum code, smoking rates, and Southern state (yes or no). Specific race/ethnicity groups included percent of the population who were African American, Native American, Non-white Hispanic, and Asian American (using White as the referent category in regression models). Rural–urban continuum was scored on a nine-point scale from least to most rural. Physician supply was the number of active MDs and DOs per 1,000 population. A

Table 1 Descriptive summary of study variables by county category

	County category			
	No mining	Non-Appalachian mining	Appalachian mining ≤ 4 million tons	Appalachian mining > 4 million tons
Number of counties	2,914	97	66	63
Total population	274,502,126	4,234,505	5,287,206	3,762,685
Age-adjusted annual number of deaths				
Chronic heart disease[a]	303,319	9,948	7,421	8,550
Acute heart disease[b]	302,316	11,028	8,313	8,117
Chronic respiratory disease[c]	138,777	4,921	3,601	3,871
Acute respiratory disease[d]	67,513	2,423	1,726	1,639
Chronic kidney disease[e]	44,418	1,526	1,252	1,284
Acute kidney disease[f]	171	3	5	4
Covariates				
Smoking rate	23.0	24.0	27.7	29.2
Percent male	49.9	50.0	49.5	49.1
Percent African American	9.3	4.9	2.6	3.2
Percent Native American	1.9	4.9	0.2	0.2
Percent Hispanic	6.7	6.7	0.9	0.7
Percent Asian American	1.0	0.5	0.4	0.4
Percent with high school education	77.7	77.9	71.4	70.2
Percent with college education	16.8	14.8	12.3	11.5
Physicians per 1,000	1.3	1.2	1.3	1.5
Poverty rate	13.4	14.0	16.3	18.2
Percent Southern county	25.4	1.0	45.5	31.7
Mean urban–rural code	5.1	5.1	5.2	5.3

[a] Includes hypertensive heart disease (ICD-10 code I11), atherosclerotic cardiovascular disease so described (I25), all other forms of chronic, ischemic heart disease (I25.8), and essential (primary) hypertension and hypertensive renal disease (I10, I12)

[b] Includes acute myocardial infarction (I21), other acute ischemic heart diseases (I24), acute and sub-acute endocarditis (I33), diseases of pericardium and acute myocarditis (I31, I40), and heart failure (I50)

[c] Includes chronic and unspecified bronchitis (J40-J42), emphysema (J43), asthma (J45), and other chronic lower respiratory diseases (J44)

[d] Includes pneumonia (J12–J18), acute bronchitis and bronchiolitis (J20–J21), and unspecified acute lower respiratory infection (J22)

[e] Includes chronic glomerulonephritis, nephritis and nephropathy not specified as acute or chronic, and renal sclerosis unspecified (N03–N05), and renal failure (N17–N19)

[f] Includes acute and rapidly progressive nephritic and nephrotic syndrome (N00, N01)

dichotomous Southern variable was created to capture larger regional effects that partially overlap with Appalachia; Southern states included Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia. CDC smoking rates were available for states and some county-based metropolitan areas. In an effort to improve smoking data, the state public health websites for all 50 states were reviewed and more specific county-level smoking rate data were found for 30 states, sometimes for individual counties and sometimes for groups of counties. The state average was used only when the more specific rate was not available. Appalachian counties included the 417 counties and independent cities in 13 states as defined by the Appalachian Regional Commission (ARC 2007).

Analyses were conducted using Poisson multiple regression with a log link function to test for the association between residence in coal mining areas and mortality rates with control for covariates. The primary independent variable of interest is a categorical measure of coal mining exposure with four levels: no coal mining, non-Appalachian mining, Appalachian mining up to 4 million tons, and Appalachian mining greater than 4 million tons.

Results

Table 1 contains descriptive characteristics of the counties by the four exposure groupings: no mining, non-Appalachian mining, Appalachian mining up to 4 million tons, and

Appalachian mining greater than 4 million tons. Appalachia has higher smoking rates, higher poverty rates, and lower education levels, but smaller race/ethnicity minority populations, compared to the nation. Acute kidney disease was a rare cause of mortality, and therefore this mortality category was dropped from further analysis.

Bivariate correlations among independent variables were examined for multicollinearity. Two variables, poverty rate and percent without health insurance, were correlated at $r = 0.81$, and so the insurance rate variable was dropped from regression models.

The next steps of the analysis examined age-adjusted mortality rates, and tested whether there were mortality effects linked to coal mining after accounting for covariates. Age-adjusted rates before adjusting for covariates are shown in Tables 2 and 3 for males and females, respectively. Mortality rates are higher in Appalachian mining areas compared to other areas in every instance. Mortality rates for these conditions are higher for men than for women, but this is the case for both mining and non-mining areas.

Poisson regression model results adjusting for covariates are presented in Tables 2 and 3, one table each for males and females. The rate ratios (RR) were found after exponentiating the log values back to the original scale; these figures represent the proportional increment in mortality rates per 100,000 relative to the non-mining reference category. For Appalachian mining areas, significantly higher mortality rates showed the same pattern for males and females. Among the Appalachian counties with the highest mining level, higher mortality rates were found for both males and females for total and chronic heart disease, total and chronic respiratory disease, and chronic kidney disease. Appalachian mining effects were stronger and more frequent in areas where mining was highest compared to areas of less-intense mining.

Coal mining areas outside Appalachia showed a similar but not identical pattern for males and females: for both sexes there were higher total and acute respiratory mortality, and higher acute heart disease mortality. Females, but not males, had significantly higher total heart disease mortality and chronic kidney disease mortality; males but not females had significantly higher mortality from chronic respiratory illness.

There were also instances where mortality was significantly lower than expected. For Appalachian coal mining areas, lower mortality was found for acute forms of heart and respiratory illness. In other words, higher mortality in Appalachian mining areas was specific to total and chronic forms of illness, while for non-Appalachian mining areas

Table 2 Male age-adjusted mortality rates per 100,000 population by mining category with 95% confidence interval (CI) in parentheses, followed by rate ratios (RR) and 95% CI adjusted for all covariates with non-mining as the referent

	Appalachian mining > 4 million	Appalachian mining up to 4 million	Non-Appalachian mining	Non-mining
Total heart				
Age-adjusted mortality	331 (316–346)	298 (287–309)	270 (257–283)	261 (259–263)
RR	1.07 (1.05–1.09)	1.01 (0.99–1.02)	1.01 (0.99–1.02)	–
Chronic heart				
Age-adjusted mortality	171 (160–181)	139 (129–149)	127 (119–136)	130 (128–131)
RR	1.28 (1.25–1.30)	1.06 (1.04–1.08)	0.96 (0.94–0.98)	–
Acute heart				
Age-adjusted mortality	160 (145–175)	159 (146–172)	143 (133–153)	132 (130–134)
RR	0.89 (0.87–0.91)	0.95 (0.93–0.97)	1.06 (1.04–1.08)	–
Total respiratory				
Age-adjusted mortality	113 (104–121)	105 (98–113)	96 (92–100)	90 (89–91)
RR	1.03 (1.00–1.05)	0.97 (0.95–0.99)	1.05 (1.02–1.07)	–
Chronic respiratory				
Age-adjusted mortality	81 (75–87)	74 (69–79)	67 (64–71)	63 (62–64)
RR	1.07 (1.04–1.10)	0.99 (0.97–1.03)	1.04 (1.02–1.06)	–
Acute respiratory				
Age-adjusted mortality	32 (28–36)	31 (27–35)	28 (26–31)	28 (27–28)
RR	0.94 (0.89–0.98)	0.92 (0.88–0.96)	1.05 (1.01–1.09)	–
Chronic kidney				
Age-adjusted mortality	25 (23–27)	22 (20–24)	18 (17–20)	19 (18–19)
RR	1.19 (1.13–1.25)	1.10 (1.05–1.16)	1.02 (0.98–1.06)	–

Table 3 Female age-adjusted mortality rates per 100,000 population by mining category with 95% confidence interval (CI) in parentheses, followed by rate ratios (RR) and 95% CI adjusted for all covariates with non-mining as the referent

	Appalachian mining > 4 million	Appalachian mining up to 4 million	Non-Appalachian mining	Non-mining
Total heart				
Age-adjusted mortality	213 (202–224)	192 (183–201)	174 (165–182)	165 (164–167)
RR	1.06 (1.04–1.08)	1.00 (0.98–1.02)	1.03 (1.02–1.05)	–
Chronic heart				
Age-adjusted mortality	109 (102–116)	92 (85–99)	83 (77–89)	84 (83–85)
RR	1.18 (1.15–1.21)	1.03 (1.00–1.05)	0.97 (0.95–0.99)	–
Acute heart				
Age-adjusted mortality	104 (94–114)	100 (92–108)	91 (85–96)	82 (80–83)
RR	0.95 (0.93–0.97)	0.97 (0.94–0.99)	1.10 (1.08–1.12)	–
Total respiratory				
Age-adjusted mortality	73 (68–78)	65 (61–70)	63 (59–66)	59 (58–59)
RR	1.03 (1.00–1.06)	0.94 (0.91–0.97)	1.05 (1.02–1.07)	
Chronic respiratory				
Age-adjusted mortality	61 (57–66)	55 (51–58)	51 (48–53)	48 (47–48)
RR	1.11 (1.07–1.15)	0.94 (0.90–0.98)	1.01 (0.98–1.04)	–
Acute respiratory				
Age-adjusted mortality	26 (23–29)	26 (23–29)	25 (23–27)	23 (23–24)
RR	0.89 (0.84–0.94)	0.92 (0.87–0.97)	1.13 (1.08–1.18)	–
Chronic kidney				
Age-adjusted mortality	18 (16–19)	17 (16–19)	14 (13–15)	13 (13–14)
RR	1.13 (1.06–1.21)	1.14 (1.07–1.21)	1.08 (1.02–1.14)	–

mortality was elevated for acute heart and respiratory disease, and chronic kidney disease for females.

Finally, county-level coal mining data are reported for the nation by the Energy Information Administration only back to 1999. However, disease consequences of exposure are hypothesized to be long-term phenomena. Longer historical records of county-level coal mining are available on the websites of two state Geological Surveys, those for West Virginia and Kentucky; an examination of these sources indicated that 100% of counties categorized in the highest coal-mining group for the current study had high levels of coal mining extending back at least to 1986. Appalachian areas with large coal reserves have been mining coal for decades.

Discussion

Total and chronic heart, respiratory and kidney disease mortality rates are significantly higher in coal mining areas of Appalachia compared to non-mining areas of the country. Coal mining industrial activities may expose residents to environmental contaminants, or these geographic areas may be associated with additional behavioral or demographic characteristics not captured through other covariates. The same effects are found for both males and females in Appalachia.

The different pattern of results in coal mining areas outside Appalachia was not expected. The different results may reflect differences in population demographics, migration patterns, mining practices, geographic topography, or population density [i.e., the population density of Appalachian coal mining areas (118 per square mile) is significantly higher than non-Appalachian mining areas (64 per square mile)]. Differences may also reflect variation in medical diagnostic practices that favor acute or chronic classifications; when considering total mortality rates, mining areas inside and outside Appalachia were elevated compared to non-mining areas.

Limitations of the study include the reliance on secondary county-level data. Causes of individual mortality cannot be identified, and the precise pathway between residence in coal mining areas and mortality is unknown. The phenomenon of environmental exposure occurs at an aggregate level, and as there is a risk of an ecological fallacy, so is there a risk of an atomistic fallacy by failing to account for the aggregate nature of the effect (Willis et al. 2003). More definitive research should be conducted using multi-level modeling of aggregate ecologic impacts on individual outcomes. An additional critical next research step is to collect direct air and water samples in coal mining communities to test the hypothesis that increased mortality from these chronic diseases is linked to poorer air and water quality.

Another limitation is the use of smoking rates that were imprecisely measured. Smoking effects, including exposure to second-hand smoke linked to poorer socioeconomic conditions, may be underestimated. The smoking variable, however, did predict higher mortality rates across conditions and so operated as expected.

Not all risk factors could be measured, for example, kidney disease risks associated with diabetes or hypertension were not assessed. Behaviors such as physical activity levels and alcohol consumption could not be included. Demographic or cultural variables not captured through available covariates may be contributing factors; these variables might include Appalachian cultural beliefs such as fatalism (Coyne et al. 2006) that increase risk for poor health behaviors or delay early health care intervention, or weak tobacco control policies that increase second-hand smoke exposure.

Future research should collect direct measures of smoking, occupational exposure, duration of environmental exposure, and individual-level health and disease measures to confirm the findings suggested by this research. Research to examine the different mortality patterns in Appalachian and non-Appalachian areas is indicated. Additional research is also needed to identify exposure types, levels, and mechanisms of action that can account for higher mortality in coal mining areas. For example, research can determine if pollution from mining itself is a contributing factor or whether the coal processing, cleaning and transportation activities that take place after mining are more important, and can determine through direct air and water quality monitoring if one transmission route or the other, or both, contribute to poor health outcomes. The pattern of results and prior research suggest that water quality may be a factor for kidney disease, that air quality may be a factor for respiratory disease, and that either air or water problems may be related to heart disease.

Until recently, research on the community health impacts of Appalachian coal mining had been unavailable, and only anecdotal evidence (Goodell 2006; Loeb 2007) attested to the health impacts of living in proximity to mining activities. A body of evidence is beginning to emerge, however, that confirms the beliefs of local residents at least to some extent, and suggests that coal mining-related community health problems are real (Hendryx and Ahern 2008; Hendryx et al. 2007, 2008; Orem 2007; Shiber 2005; Stout and Papillo 2004). As evidence accumulates to reveal a previously unknown contributing factor to the infamous health disparities plaguing Appalachia, it becomes critical to address issues of environmental equity and to reduce environmental and socioeconomic disparity through economic and policy interventions. These interventions may include establishing and enforcing stricter air and water quality standards in coal mining communities.

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