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Chronic Cardiovascular Disease Mortality in Mountaintop Mining Areas of Central Appalachian States

Laura Esch, BS & Michael Hendryx, PhD

Department of Community Medicine, West Virginia University, Morgantown, West Virginia

For further information, contact: Laura Esch, School of Medicine, West Virginia University, P.O. Box 9190, Morgantown, WV 26506; e-mail lesch@hsc.wvu.edu.

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Abstract

Purpose: To determine if chronic cardiovascular disease (CVD) mortality rates are higher among residents of mountaintop mining (MTM) areas compared to mining and nonmining areas, and to examine the association between greater levels of MTM surface mining and CVD mortality.

Methods: Age-adjusted chronic CVD mortality rates from 1999 to 2006 for counties in 4 Appalachian states where MTM occurs (N = 404) were linked with county coal mining data. Three groups of counties were compared: MTM, coal mining but not MTM, and nonmining. Covariates included smoking rate, rural-urban status, percent male population, primary care physician supply, obesity rate, diabetes rate, poverty rate, race/ethnicity rates, high school and college education rates, and Appalachian county. Linear regression analyses examined the association of mortality rates with mining in MTM areas and non-MTM areas and the association of mortality with quantity of surface coal mined in MTM areas.

Findings: Prior to covariate adjustment, chronic CVD mortality rates were significantly higher in both mining areas compared to nonmining areas and significantly highest in MTM areas. After adjustment, mortality rates in MTM areas remained significantly higher and increased as a function of greater levels of surface mining. Higher obesity and poverty rates and lower college education rates also significantly predicted CVD mortality overall and in rural counties.

Conclusions: MTM activity is significantly associated with elevated chronic CVD mortality rates. Future research is necessary to examine the socioeconomic and environmental impacts of MTM on health to reduce health disparities in rural coal mining areas.

Key words Appalachia, cardiovascular health, coal mining, mortality, rural.

Heart disease is the leading cause of death in both the nation and in Appalachia, and mortality rates within Appalachia are higher than the nation.[1,2] Lifestyle determinants of cardiovascular disease (CVD), including smoking and obesity, are disproportionally present in the Appalachian region, and in addition, the geographic, social, and economic factors of the area increase risk of exposure to environmental pollutants that threaten cardiovascular health.[1,3,4]

Exposure to air pollution from industry and other contaminant sources is associated with increased CVD mortality from ischemic heart disease.[5-7] Heart disease and myocardial infarctions can be triggered by increases in particulate matter (PM), even after acute exposure to elevated levels of PM.[8] Exposure to PM less than 10 μm in diameter (PM_{10}) is associated with fatal coronary heart disease[9] and PM less than 2.5 μm in diameter ($PM_{2.5}$) plays a role in the progression of atherosclerosis.[10] Air pollution is associated with emergency room admissions for a myriad of CVDs including ischemic heart diseases, myocardial infarction, atherosclerosis, and congestive heart failure.[7,10,11] Arsenic, which is present in

domestic well drinking water supplies through parts of Appalachia,[12] is associated with an increase in myocardial infarction, atherosclerosis, and blood pressure among adults.[13-15] Exposure to cadmium, an impurity in coal that is present throughout Appalachia, has been shown to increase risk of cardiovascular and coronary heart disease mortality among adult males.[16] Exposure to lead, which is also present in coal, is suggestive of cardiovascular outcomes such as elevated blood pressure, future ischemic heart disease,[17] and cardiovascular mortality.[18,19]

Appalachia is one of the nation's leading coal production regions, and the processes of coal mining and cleaning release health-hazardous environmental pollutants into the air and water.[1,3,4,20-23] Coal mining areas will continue to be impacted by these pollutants because coal production and consumption is projected to increase in the next 25 to 30 years[24] and because pollutants from coal mining remain in local environments long after mining at a particular location ceases.[25] Residents of Appalachian coal mining counties report exposure to coal-related air and water contaminates, which has implications for cardiovascular health.[4,20-22,26,27] Overall, health disparities are more prominent in Appalachian coal mining counties compared to nonmining counties.[28] Prior research has indicated significantly higher age-adjusted total and chronic heart disease mortality rates from hypertensive, atherosclerotic, and ischemic heart diseases, as compared to nonmining areas.[29] Appalachian coal mining counties also have a higher risk of self-reported CVD, angina or coronary heart disease, and heart attack.[30] While previous studies have examined chronic CVD morbidity and mortality in coal mining areas characterized by coal production levels, cardiovascular risks associated with the type of coal mining, in particular, mountaintop mining (MTM), have not been investigated.

Mountaintop mining with valley fills (abbreviated as MTM) is a relatively new form of mining involving the removal of mountaintops to excavate coal seams underneath. Surface mining techniques are then used once coal seams are exposed, and the removed overburden from the mountaintop is deposited in nearby valleys.[31] Areas around surface coal mines have significantly worse air quality compared to nonmining areas,[32] and water quality is greatly affected by the changes in mountaintop and filter bed topography resulting from MTM practices.[25]

Coal mining is primarily a rural phenomenon. Within the 4 states included in this study (Kentucky, Tennessee, Virginia, and West Virginia), there are 404 counties, 229 (57%) of which are classified as nonmetropolitan. Coal mining occurs in 90 of the counties, of which 68 (76%) are nonmetropolitan. The current study has 3 new objectives over previous research on population CVD in coal mining areas: (1) to determine if chronic CVD mortality rates are elevated particularly among residents of MTM mining areas; (2) to examine whether CVD mortality rates increase as a function of greater quantities of surface mining activity in MTM; and (3) to examine whether elevated CVD mortality related to mining is present in both rural and urban areas.

Methods

Design

This ecological study is a retrospective, county-level analysis of secondary data to examine chronic CVD mortality rates from 1999 to 2006 for all counties in the 4 central states where MTM activity occurs, including Kentucky, Tennessee, Virginia, and West Virginia.

Data

Data on county-level chronic CVD mortality were obtained from the Centers for Disease Control's (CDC) ICD 10-113 diagnostic groups. Mortality rates were provided per 100,000 population and were age-adjusted using the 2000 US standard population.[33] Annual age-adjusted rates were found for the period 1999-2006, which corresponds to the period of time available from the CDC Web site using ICD-10 codes, and collapsed across years to obtain the mean age-adjusted mortality rates for the combined period.

Chronic diseases are generally defined as diseases that develop over an extensive time period or are terminal. However, after examining disease etiology for all cardiovascular diagnostic groupings, diseases that resulted from chronic risk factors were also defined as chronic for this study. Ischemic diseases and other diseases where blood supply to the heart decreases were considered chronic (GR113–056 Hypertensive heart disease; GR113–057 Hypertensive heart and renal disease; GR113–059 Acute myocardial infarction; GR113–060 Other acute ischemic heart diseases; GR113–062 Atherosclerostic CVD, so described; GR113–063 All other forms of chronic ischemic heart disease; GR113–067 Heart failure; GR113–069 Essential [primary] hypertension and hypertensive renal disease; GR113–071 Atherosclerosis). Mortality from diseases that were rare among the adult population (GR113–055 Acute rheumatic fever and chronic rheumatic heart disease), resulted from exposure to bacterial or viral agents (GR113–065 Acute and subacute endocarditis, GR113–066 Diseases of pericardium and acute myocarditis) or traumatic injury (GR113–073 Aortic aneurysm and dissection), or were cerebrovascular diseases (GR113–070 Cerebrovascular diseases, including

stroke) were not included in the chronic heart disease mortality rates. Furthermore, disease categories that did not have a specified etiology (GR113–068 All other forms of heart disease; GR113–074 Other diseases of arteries, arterioles, and capillaries; GR113–075 Other disorders of circulatory system) were also excluded.

Coal mining data were obtained from the Department of Energy, Energy Information Administration (EIA),[34] and from a map of surface mining areas in central Appalachia.[35] The map was overlaid with EIA county-level coal production figures to identify the coal mining counties in central Appalachia where MTM activity takes place. Three coal mining dummy variables were calculated, including counties in MTM areas, counties where mining took place but outside of the MTM area, and nonmining counties in the 4 states, which served as the referent group in the statistical models.

Mining activity was examined for 1994-2006, beginning with the earliest year county-level surface and underground tonnage statistics were reported publicly on the EIA Web site and ending with the same year as the last year of CDC mortality data. For convenience, we call the area of central Appalachia where surface mining is most intense and where MTM occurs the MTM area. However, it should be recognized that surface mining, but not true MTM, occurs outside of this central Appalachian MTM zone, and underground mining and other mining activities (eg, coal processing) take place in both MTM areas and in other mining areas. In other words, the contrast between central Appalachian MTM and other mining areas is relative, not absolute. A map of the 4 states showing these mining areas is provided in Figure 1.

Levels of surface mining are measured in thousands of tons of coal mined using surface techniques as reported by the EIA for the combined years 1994-2006. Levels of mining were not normally distributed and so we found the natural log transformation of these variables. We calculated the log of thousand tons of surface coal mined over time in MTM areas to test if greater levels of mining in MTM areas were associated with higher mortality rates.

Previously identified risk factors for CVD served as covariates.[26,36–39] Data from the 2005 Area Resource File and other sources were used to measure covariates. Variables included smoking rate; rural-urban status; percent male population; the number of active, nonfederal primary care physicians per 1,000 population; adult obesity rate; diabetes rate; percent of the population below the federal poverty level; percent of the population who were African American, Native American, and Hispanic; percent without a high school education; percent with college or higher education; and whether the county was located within Appalachia. Most of these indicators were from the 2000 US Census, although poverty rate was the average of the years 2000-2002. Prevalence of smoking for each county was obtained from the CDC's Behavioral Risk Factor Surveillance System (BRFSS) data based on samples conducted in 2003 and 2006, supplemented with additional county estimates based on review of state public health department Web sites. Adult obesity rates and adult diabetes rates for each county were taken from the US Department of Agriculture (USDA) Food Atlas,[40] which in turn is based on CDC BRFSS survey and US Census estimates for the years 2006-2008. Appalachian counties were identified from Appalachian Regional Commission designations. Rural-urban continuum codes from the USDA were used to categorize counties into metropolitan (codes 1-3) or nonmetropolitan (codes 4-9) areas. The terms metropolitan and urban, and the terms nonmetropolitan and rural, are used interchangeably in this study.

Analysis

Age-adjusted mortality rates were linked with coal mining data and covariates at the county level. Descriptive

Figure 1 Coal Mining Areas in Central Appalachian States, 1994-2006

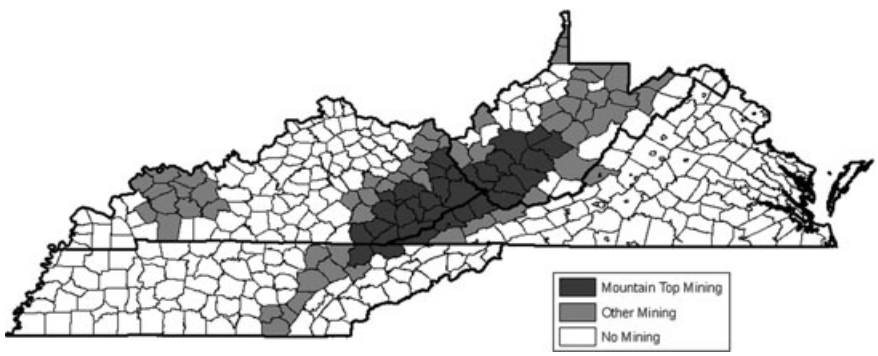

Table 1 Descriptive Summary of Population-Level Mortality and County-Level Study Variables (N = 404), 1999-2006, Kentucky, Tennessee, Virginia, and West Virginia

Variable	Overall Mean (Standard Deviation)	MTM Areas	Mining in Non-MTM Areas	Nonmining Areas
N	404	32	58	314
Age-adjusted chronic cardiovascular mortality rate per 100,000*	236.80 (48.04)	291.96 (50.21)	250.54 (33.47)	228.64 (45.88)
Coal mining activity (thousand tons)				
Log of 1,000 surface tons mined MTM areas	0.79 (2.72)	9.97 (1.36)	0	0
Log of 1,000 surface tons mined non-MTM areas	0.81 (2.31)	0	5.67 (3.12)	0
Covariates				
Smoking rate (%)**	26.71 (4.64)	29.99 (4.13)	28.09 (4.16)	26.13 (4.59)
Urban county (%)***	43.31(49.61)	9.38 (29.61)	32.76 (47.34)	48.73 (50.06)
Percent male	49.61 (1.77)	49.24 (1.19)	49.75 (2.42)	49.63 (1.67)
Physicians per 1,000	1.44 (1.79)	1.25 (0.89)	1.31 (1.56)	1.48 (1.90)
Obesity rate (%)*	29.99 (2.55)	32.70 (2.28)	31.03 (2.10)	29.52 (2.43)
Poverty rate (%)*	14.77 (5.75)	24.08 (5.11)	17.83 (5.03)	13.26 (4.74)
Percent African American**	9.61 (13.56)	2.09 (2.75)	2.46 (3.88)	11.70 (14.62)
Percent Native American	0.27 (.40)	0.19 (0.15)	0.21 (0.13)	0.29 (0.44)
Percent Hispanic**	1.74 (2.43)	0.64 (.20)	0.81 (0.66)	2.02 (2.68)
Percent with college education or higher**	14.50 (8.87)	9.11 (2.72)	11.15 (4.59)	15.67 (9.50)
Appalachian (%)*	46.04 (49.90)	100 (0)	81.03 (39.55)	34.08 (47.47)

*All three groups significantly different from each other at $P < .05$, post-hoc Tukey.

**MTM significantly different from both other groups at $P < .05$, post-hoc Tukey.

***MTM significantly different from nonmining areas at $P < .05$, post-hoc Tukey.

summaries of study variables were found, distributional characteristics of variables were examined, and bivariate correlations among variables were calculated to examine the data for multicollinearity. Unadjusted and adjusted linear regression analyses were used to determine the association of age-adjusted mortality rates with the 2 primary coal mining categorical variables. Models were run for all 404 counties in the 4 states and again for the 186 counties contained within the Appalachian region. Nonmining counties in these analyses were used as the referent group. We then conducted a regression analysis specific to MTM areas to determine if higher levels of mining, as measured by the log of thousands of surface tons mined, were associated with mortality rates. Finally, regression analyses were conducted overall and separately for rural counties. Statistical Analysis Software (SAS, SAS Institute Inc., Cary, North Carolina) version 9.2 was used for all analyses.

Results

Results of the bivariate correlations to test for multicollinearity resulted in dropping 2 covariates from further study because they were highly correlated with other measures. We dropped the percent without high school education because it correlated highly with college education rate (r = –0.75) and poverty rate (r = 0.81). We dropped diabetes rate because it correlated highly with obesity rate (r = 0.63).

Descriptive results for age-adjusted population mortality, coal mining variables, and county-level covariates are presented in Table 1. Table 1 shows the mean annual age-adjusted CVD mortality rates in the 3 county groups: counties with MTM, other mining counties, and nonmining counties. Mortality rates were significantly highest in MTM areas, followed by other mining areas, and were lowest in nonmining areas $F(2,401) = 32.35$, $P < .001$. Table 1 also shows that mining areas tended to have higher risks on socioeconomic and behavioral variables. Group differences were tested using general linear models followed by post-hoc Tukey tests to correct for type I error.

The population of the MTM area based on the 2000 Census was 1,109,022; the excess age-adjusted deaths per 100,000 translates to an additional 703 deaths per year in the MTM area compared to the nonmining areas of the same states from the studied conditions. The population of non-MTM mining areas (1,683,704) translates to an additional 369 deaths per year. Both mining areas combined, therefore, have an excess of 1,072 annual age-adjusted deaths for the forms of CVD included in this study.

Table 2 shows the unstandardized regression coefficients for the dummy measures for mining in MTM areas and other mining areas. Both unadjusted and adjusted

Table 2 Unadjusted and Adjusted Regression Coefficients for the Association Between Surface Mining Measured as a Categorical Variable (MTM, non-MTM, and Nonmining Referent) and Age-Adjusted Chronic Cardiovascular Mortality per 100,000 for 1999-2006, Kentucky, Tennessee, Virginia, and West Virginia. Results are shown for all counties (N = 404) and for Appalachian counties (N = 186)

	Coefficient	Standard Error	*P* Value
All counties (N = 404)			
Unadjusted			
Mining in MTM areas	63.3	8.3	<.0001
Mining in non-MTM areas	21.9	6.4	<.0007
Adjusted*			
Mining in MTM areas	15.4	7.6	<.044
Mining in non-MTM areas	−2.21	5.62	<.69
Appalachian counties (N = 186)			
Unadjusted			
Mining in MTM areas	51.5	8.0	<.0001
Mining in non-MTM areas	12.0	6.9	<.09
Adjusted**			
Mining in MTM areas	24.7	9.3	<.009
Mining in non-MTM areas	1.1	7.1	<.87

*Covariates include: percent of the population who were African American, Native American, and Hispanic; percent male population; percent with college or higher education; percent of the population below the federal poverty level; the number of active, nonfederal primary care doctors per 1,000 population; smoking rate; adult obesity rate; Appalachian county (yes/no); and metropolitan or nonmetropolitan county. Adjusted model F = 27.38, $df = 13, 390$, $P < .0001$, adjusted $R^2 = 0.46$.

**Covariates include those in the all-county model except Appalachian county. Adjusted model F = 7.53, $df = 12, 173$, $P < .0001$, adjusted $R^2 = 0.30$.

coefficients are presented for 2 analyses, 1 including all counties and 1 including only Appalachian counties. The dependent variable is age-adjusted chronic CVD mortality rate per 100,000. The unadjusted results for all counties show that both mining categories are significantly related to higher mortality rates. Within Appalachia, the unadjusted coefficient was significant only for MTM areas. After adjusting for covariates, the effects were significant only in the MTM areas in both the all-county and the Appalachian-only models.

To identify which covariates may be most important in association with higher mortality, we re-conducted the regression analyses using a backward selection approach, deleting variables sequentially that did not meet a $P < .05$ inclusion criterion. All counties were included. Four significant variables remained in the model: MTM areas, obesity rate, poverty rate, and college education rate. These results are shown in the top half of Table 3.

Because the adjusted mining effect was significant only in MTM areas, we conducted a follow-up analysis limited to the 32 MTM counties. For this analysis, the independent variable of interest was the log of thousands of tons of surface coal mined. This analysis also used a backward selection model with a $P < .05$ inclusion criterion. Higher CVD mortality was significantly associated with greater levels of surface mining in MTM areas. Mortality was also related to higher poverty, higher supply of physicians, and lower percentages of African American and Native American populations.

Table 3 Final Regression Models With Significant Covariates After Backward Elimination, Age-Adjusted Chronic Cardiovascular Mortality per 100,000 for 1999-2006, Kentucky, Tennessee, Virginia, and West Virginia

	Coefficient	Standard Error	*P* Value
Mining as categorical variable (N = 404)*			
Mining in MTM areas	16.9	7.5	<.03
Adult obesity rate	3.87	0.91	<.0001
Poverty rate	2.20	0.42	<.0001
College education rate	−1.60	0.26	<.0001
Log of tons of surface mining in MTM counties (N = 32)**			
Log of surface tons mined	11.4	5.5	<.05
Physicians per 1,000	22.5	9.6	<.03
Poverty rate	7.4	1.7	<.0002
Percent African American	−5.9	2.7	<.04
Percent Native American	−97.8	45.3	<.04

*F = 86.1, $df = 4, 399$, $P < .0001$, $R^2 = 0.46$.

**F = 5.9, $df = 5, 26$, $P < .0009$, $R^2 = 0.53$.

Rural-specific Results

There were only 3 counties classified as urban that fell within the MTM area. When we repeated the regression model for only rural counties, the same 4 variables as for the overall model remained significant: MTM area, obesity rate, poverty rate, and college education rate (results not shown).

Discussion

Chronic CVD mortality rates in central Appalachian states are significantly higher in mining compared to nonmining areas, and they are highest in MTM areas (Table 1). In non-MTM mining zones, increased mortality risk appeared to be the result of adverse socioeconomic and behavioral conditions that drive poor health. These socioeconomic and behavioral risks for mortality are also elevated in MTM mining areas and help to account for higher mortality rates (Table 3). However, after controlling for these risk factors, mortality rates remained significantly elevated in MTM mining areas (Tables 2 and 3). MTM is an activity that occurs primarily in rural areas, and the relationship between increased MTM activity and CVD mortality was present when the analysis was

limited to rural counties as well as when all counties were included.

The results supplement prior research demonstrating higher cardiovascular mortality for coronary heart disease and heart attack in coal mining areas.[30] Specifically, the current study demonstrates that higher adjusted chronic CVD mortality rates are concentrated in MTM areas relative to non-MTM and nonmining areas. Although indirect, this is consistent with a hypothesis that the well-established, adverse environmental impacts of MTM have human health consequences.[21,22,26] However, it is unknown what air, water, and other contaminant exposures may be most associated with elevated chronic CVD mortality in MTM mining areas.

We measured mining activity coincident with the years of mortality data. However, it is not clear what the correct time lags should be between mining activity and health impacts, as there is evidence for both delayed[6,9,17,18] and acute[5,8,41] impacts of environmental exposures. In the latter case, the acute impacts occur among persons with preexisting illness.

A primary limitation of this study is the ecological design and the use of secondary-level mortality data. Causality between MTM mining and chronic CVD mortality cannot be definitively established because it is unknown if those residing near the surface mining areas are the individuals in the county experiencing mortality from chronic CVD. Individual-level cardiovascular mortality and risk factor data would improve knowledge of chronic CVD etiology in rural mining areas.

A second limitation of this study is related to risk factor and mortality data quality. Measures of risk factors are indirect and BRFSS smoking rates, obesity rates, and other county-level covariate measures are to some extent imprecise and were not available in all cases for the same time period. Variations exist within the county such that county-level data may misrepresent the subpopulation living within MTM mining areas. Mortality data are compressed data files and indicate the underlying cause of death, which may not reflect the true cause(s) of death. Mortality data for counties with 5 or fewer cases of chronic CVD mortality per year were suppressed by registries to protect the confidentiality of those cases. Still, CDC mortality data include every death recorded by state and local health departments and allow data to be compared across geographic locations and time periods. In addition to limitations on the mortality data, the identification of MTM areas is imperfect. More precise data identifying MTM areas would provide information on the specific impact of MTM on chronic CVD mortality.

Finally, many primary risk factors for chronic CVD are included as covariates in this study to the extent provided by the data, but all known chronic CVD risk factors were not included in the model. For example, risk factors related to lifestyle, including diet and exercise choices, lipid parameters, blood pressure measures, and family history were not considered. Still, this exploratory study confirms that the type of coal mining, specifically large-scale surface mining activity, should be considered when examining health outcomes and chronic disease mortality.

Our study was limited to mining activity among 4 states in the United States. Coal mining, however, occurs in many other places throughout the world including Australia, which ranks fourth in world coal production behind China, the United States, and India. There is limited research on population health consequences of Australian coal mining, but at least one study has documented elevated rates of childhood asthma proximate to surface mining in Australia.[42]

The correspondence between mining activity and poor socioeconomic conditions is itself a concern and is consistent with previous research identifying mining-dependent economies as among the weakest in the Appalachian region.[43] Adverse socioeconomic conditions are a fundamental cause of poor population health outcomes.[44,45] Areas of central Appalachia where mining is present have the highest poverty rates and the lowest rates of college education in the region. CVD mortality is a consequence of these factors in addition to possible MTM-related environmental exposures.

We also observed in the model specific to MTM areas that higher adjusted mortality rates were related to lower rates of African American and Native American populations. This was somewhat unexpected, but it is probably related to the fact that MTM areas generally have small minority populations, and that those areas with the heaviest MTM activity, and the highest mortality rates, also have the lowest percentages of minority groups. Chronic CVD mortality associated with MTM is potentially modifiable through policy interventions. The Environmental Protection Agency (EPA) regulates placement of valley fill sites, MTM regulations are set forth in the Surface Mining Control and Reclamation Act of 1977, and additional EPA restrictions were established in April 2010,[46] but air and water contaminates from MTM sites may still pose major health threats to residents.[22,31] A recent approval of a new EPA permit issued after the April 2010 regulations suggests that enforcement of the new standards may be lacking.[47] Taken with other literature on coal mining and community health, this study shows that residents of rural coal mining areas within central Appalachian states have significant cardiovascular health disadvantages and identifies a new health burden specifically in MTM areas.

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