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Chronic Respiratory Effects of Exposure to Diesel Emissions in Coal Mines

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ABSTRACT. A 5-yr prospective design was employed to test the hypothesis that exposure to diesel emissions leads to chronic respiratory effects among underground coal miners. Changes in respiratory function and development of chronic respiratory symptoms were measured during a 5-yr study period (i.e., 1977 to 1982) in 280 diesel-exposed and 838 control miners from Eastern and Western United States underground coal mines. Spirometry measures of respiratory function included forced expiratory volume in 1 sec ($FEV_{1.0}$), forced vital capacity (FVC), and forced expiratory flow rate at 50% of FVC (FEF_{50}). Chronic respiratory symptom measures, which included chronic cough, chronic phlegm, and breathlessness, were obtained by questionnaires, as were smoking status and occupational history. Based upon these data, the pattern of evidence did not support the hypothesis either in an age-adjusted comparison of diesel vs. nondiesel miners or in an internal analysis by cumulative years of diesel exposure.

HEALTH CONSEQUENCES of diesel engine emissions on underground miners have long concerned occupational health specialists. In underground coal mines, the concerns include interaction and potentiating effects between diesel gases and coal mine dust.[1-3] Health effects of diesel emissions have been the subject of several symposia.[4-6] One outcome of these symposia has been a program of research at the Appalachian Laboratory for Occupational Safety and Health (ALOSH) directed toward a systematic evaluation of the health and safety aspects of the use of diesels in underground coal mines. An evaluation of prior diesel exposure on respiratory function and symptoms has been conducted by Reger et al.[7] A report on acute respiratory effects during an 8-hr work shift has been presented by Ames et al.[8] Safety aspects of diesel engine use in underground coal mines have been analyzed by Ames, Reger, and Wheeler.[9] This study examines whether chronic respiratory effects are related to diesel emissions exposure in underground coal mines based upon a 5-yr prospective study.

Diesel emissions contain gases known to be noxious to the respiratory system, including carbon monoxide (CO), oxides of nitrogen (NO_2 and NO_x), and particulates.[4,5,10] A previous study of respiratory effects of diesel engine emissions during the 8-hr work shift in coal miners did not detect significant acute diesel effects.[8] The study of acute respiratory effects, however, leaves unanswered the question of chronic respiratory effects. Furthermore, even though diesel emissions are known to have aspects harmful to the respiratory system, questions remain regarding the dilution of the emissions, duration of exposure, interactions with coal mine dust or other exogeneous chemicals and compounds, and cigarette smoking effects.

This study was designed to address the question: Does diesel emissions exposure in underground coal mines lead to chronic respiratory effects among coal miners? Three specific concerns were addressed: (1) whether diesel exposure is related to pulmonary function decrements; (2) whether diesel exposure is related to respiratory symptom incidence; and (3) whether a dose–response relationship exists between cumulative years of diesel exposure and pulmonary function decrements and respiratory symptom incidence.

DATA AND METHODS

Respiratory symptom and function measurements and personal and occupational histories were determined for 280 miners who worked underground where diesel engines were used and from 838 nondiesel (control) miners from neighboring underground coal mines. All mines were bituminous coal mines located in Kentucky, Colorado, and Utah. Neighboring mines were selected in an attempt to provide worker and mine comparability. (It is known, however, that exact comparability is difficult, if not impossible, to obtain; differences often include union status, age of mine, average age and education of workforce, and mine size.) Miners with more than 1 yr of underground mining experience who were examined in 1977 and re-examined in 1982 are the subjects of this study. Five-year changes were computed for measures of: (1) respiratory function, including forced vital capacity (FVC), forced expiratory volume in 1 sec ($FEV_{1.0}$), and forced expiratory flow rate at 50% of FVC (FEF_{50}); and (2) incidence of respiratory symptoms, including chronic cough, chronic phlegm, and breathlessness.

Measurements of pulmonary function involved at least five spirometric maneuvers by each subject on a dry rolling-seal spirometer Model 840 (Ohio Instruments, Madison, WI). The flow and volume signals from the spirometer were recorded on FM analog tape (Model 3960; Hewlett-Packard, Waltham, MA) and were analyzed later by a Digital computer (Model LSI-11; Digital Equipment Corp., Maynard, MA). The FVC, $FEV_{1.0}$, peak flow, and flow rates at intervals of 5% of the FVC were measured and calculated from each flow-volume curve. The largest FVC and $FEV_{1.0}$ values were used regardless of the curve or curves on which they occurred. Flow rates were obtained by aligning all of the flow-volume curves at total lung capacity and using the largest observed flow at the volume of interest (maximal envelope flow-volume curves). Five-year changes were computed by subtracting the 1977 measures from the 1982 measures so that decrements would be indicated by negative values.

Area samples taken in 1977 revealed the levels of diesel combustion gases and mine dust particulate to be very low; in no case did mean values of gases or aggregate coal mine dust and diesel particulate exceed 25% of current standards.[8]

Data are presented separately for Eastern and Western miners because no comparable controls existed for Eastern diesel mines from 1977 to 1982. Change functions for these controls were generated using an earlier 5-yr time span, roughly 1972–1977, a time when coal mine dust levels were probably higher.

Since the age distribution of the diesel and control miners differed, respiratory symptom and rate measures were adjusted, using direct age-adjustment[11] in 10-yr age intervals, to the 1977 age distribution of diesel and nondiesel combined. To exclude the respiratory effects of coal mine dust, and to exclude cigarette smoking effects, diesel vs. nondiesel comparisons were controlled for years of underground mining and for smoking status. Current smokers were defined as those who smoked cigarettes at the start and conclusion of the 5-yr study period; others were listed as "not current smokers." The dichotomy was used since previous studies have shown that respiratory symptoms and pulmonary function decrements tend to moderate following smoking cessation.[12-14] Cigarette smoking is an important control in this analysis of respiratory effects since diesel exhaust and cigarette smoke share several qualities, notably CO, CO_2, and particulates.

A one-tailed *t* test was used to assess statistical significance for respiratory function when the direction of the difference was consistent with the hypothesis.

As a further line of argument beyond the diesel vs. nondiesel comparison, an internal analysis was performed on the diesel-exposed miners to test for a dose-response relationship between respiratory effects and cumulative years of underground diesel exposure. The levels of diesel contaminants prior to 1977 are not documented in this study. For pulmonary function changes, a least-squares means analysis[15] was performed using as the predictive model: age, height, weight, cumulative years of underground diesel exposure, and smoking status. For respiratory symptom incidence, a logistic analysis[16] was performed using the same predictors.

Baseline characterizations. In both the Eastern and Western mines, the diesel miners were not only slightly younger on the average, but also had only half as many years of underground mining experience as the nondiesel miners (Table 1). Western miners, diesel or nondiesel, were less likely to be current smokers than Eastern miners (Table 1). Given these differences, diesel vs. nondiesel comparisons are age-adjusted, cross-tabu-

Table 1.—Baseline Values for Age, Years Underground, and Smoking Status by Diesel, Nondiesel Status, and Geographic Location

	West		East	
Baseline Characteristics	Diesel	Nondiesel	Diesel	Nondiesel
Age (mean) (yr)	36.1	38.6	37.0	44.4
Years underground (mean)	6.6	13.8	8.8	17.4
Smoking status (% current)	34.8	41.9	55.8	53.3
Number of miners	200	133	80	705

Table 2.—Baseline Characterization for Mean Respiratory Functions and Respiratory Symptoms by Diesel, Nondiesel Status, and Geographic Location

Baseline Respiratory Function and Respiratory Symptoms*	West		East	
	Diesel	Nondiesel	Diesel	Nondiesel
FVC (L)	5.4	5.1	5.0	5.1
$FEV_{1.0}$ (L)	4.3	3.9	4.0	3.9
FEF_{50} (L/sec)	5.3	4.4	5.2	4.7
Cough (% 3+ months/yr)	15.5	26.3	27.1	33.0
Phlegm (% 3+ months/yr)	18.5	27.2	23.8	36.6
Breathlessness (%)	4.3	14.6	8.5	28.6

* Baseline values are for 1977 except for Eastern nondiesel mines, which are for 1972.

lated by categories of smoking status and years of underground mining, and are presented separately by geographic region.

Respiratory function baselines, unadjusted for age, show the diesel miners generally to have slightly higher respiratory function values, thus suggesting better initial respiratory health than the control miners; this is true in Western mines and for all measures except FVC in Eastern mines (Table 2). Chronic respiratory symptom prevalence was much lower in the diesel miners than the nondiesel miners (Table 2). These values may reflect age effects as well as age-correlated conditions.

RESULTS

Respiratory function changes. Diesel miners had much smaller mean 5-yr decrements in FVC and $FEV_{1.0}$ than control miners in both the East and West (Table 3). This was true under joint control for years underground and smoking status (data not shown).

For FEF_{50}, however, changes were inconsistent: in the East, diesel miners had a smaller decrement, whereas in the West, they had a statistically significantly larger decrement than the control miners (Table 3).

Respiratory symptom changes. Diesel miners had lower incidences of chronic cough, phlegm, and breathlessness over the 5-yr time period than controls in both Eastern and Western mines (Table 4). These findings held up under joint control by years underground and cigarette smoking status (data not shown).

Cumulative diesel prediction. The internal analysis relating cumulative years of underground diesel exposure and pulmonary function changes, given adjustment for age, height, weight, and smoking status, revealed no significant dose-response relationship (Table 5). The only statistically significant diesel exposure contrasts were for FEF_{50} in Western mines, and these were inverse to the direction hypothesized. A logistic analysis of respiratory symptom incidence, using the same predictive model, revealed no additional explanation attributable to cumulative years of diesel exposure (Table 6).

DISCUSSION

This study did not reveal a pattern of chronic respiratory effects associated with exposure to diesel emissions in coal miners. No pattern either of respiratory symptom incidence (for chronic cough and phlegm, or breathlessness) or pulmonary function decrements (for FVC or $FEV_{1.0}$) was associated with underground diesel exposure. However, for FEF_{50} in Western mines, diesel miners showed significant impairment in comparison with control miners. The biologic and theoretical importance of this single relationship, which was not replicated among the Eastern miners, is questionable.

Several steps were taken to enhance comparisons of diesel with nondiesel miners. Confounding by coal dust effects and cigarette smoking effects was reduced through single and joint control. Age adjustment was also performed. Nevertheless, the lack of a pattern of

Table 3.—Five-Year Changes in Ventilatory Function by Diesel, Nondiesel Status, and Geographic Location

Respiratory Function	Mean 5-Yr Changes (ml)*† West		East	
	Diesel	Nondiesel	Diesel	Nondiesel
FVC	−99	−218	−144	−437
$FEV_{1.0}$	−122	−153	−126	−350
FEF_{50}	−290	+211‡	−174	−253

* Age-adjusted; miners with more than 1 yr underground.
† Eastern change data for 1972 to 1977.
‡ Western diesel vs. nondiesel difference significant at < .001, one-tailed *t* test.

Table 4.—Five-Year Incidence of Respiratory Symptoms by Diesel, Nondiesel Status, and Geographic Location

Respiratory Symptoms	5-Yr Incidence*† West		East	
	Diesel	Nondiesel	Diesel	Nondiesel
Cough (3+ months/yr)	14.7	22.4	23.4	27.6
Phlegm (3+ months/yr)	20.7	24.8	24.9	31.3
Breathlessness	9.3	13.1	9.8	29.5

* Age-adjusted; miners with more than 1 yr underground.
† Eastern change data for 1972 to 1977.

Table 5.—Least-Squares Means for Ventilatory Function Changes by Cumulative Years of Diesel Exposure (Diesel Miners Only)

Ventilatory Function by Cumulative Years of Diesel Exposure	Least-Squares Means of 5-Yr Changes under Simultaneous Adjustment for Age, Height, Weight, and Cigarette Smoking Status: West	East
FVC (ml)		
Cumulative diesel exposure		
< 6 yr	+46	-82
6–7 yr	-8	-96
≥ 8+ yr	-38	-196
Prob $H_o : d_i - d_j$	all NS	all NS
$FEV_{1.0}$ (ml)		
Cumulative diesel exposure		
< 6 yr	-107	-133
6–7 yr	-114	-125
≥ 8+ yr	-57	-141
Prob $H_o : d_i - d_j$	all NS	all NS
FEF_{50} (ml/sec)		
Cumulative diesel exposure		
< 6 yr	-480	-335
6–7 yr	-483	-167
≥ 8+ yr	+2	-54
Prob $H_o : d_i - d_j$	$d_1 - d_2$, NS; $d_1 - d_3$, $P < .01$; $d_2 - d_3$, $P < .01$	all NS

NS = not significant, alpha .05.

chronic respiratory effects related to occupational exposure to diesel emissions in this study of employed coal miners may be due to the low level of diesel contaminants. Also, diesel and nondiesel comparisons reflect a host of social discrepancies such as union status, age at time of entry into mining, educational background, prior work experience, and numerous other factors, in addition to the differences based on mining methods.

Additional analysis was undertaken to assess dose-response relationships by cumulative years of underground diesel exposure. This analysis also revealed no chronic respiratory effects associated with diesel exposure. The failure to document a pattern of adverse diesel effects on pulmonary function or symptoms in coal miners, either by comparison with nondiesel-exposed miners or over time by cumulative years of diesel exposure, is generally consistent with findings from studies of diesel use in other mining environments. In their study of salt miners, Gamble, Jones, and colleagues[17-19] reported a slight association of diesel exposure with phlegm (possibly confounded with salt exposure). They found no relationship between diesel exposure and other respiratory symptoms or pulmonary function changes. In another set of studies, no relationship was found between diesel exposure and measures of respiratory symptoms or pulmonary function for trona miners,[20,21] for potash miners,[20-22] or for metal and non-metal miners.[23]

Some occupational epidemiology studies report analyses of respiratory effects in relation to diesel use in non-mining environments. No respiratory effects attributable to diesel exposure, either dose-response or in comparison to an unexposed group, were reported among railroad roundhouse workers.[24] In a study of acute respiratory effects of diesel bus garage workers, Gamble et al.[25] found cough, labored breathing, chest tightness, and wheeze. Chronic respiratory effects from

Table 6.—Logistic Analysis of Respiratory Symptom Incidence by Cumulative Years of Diesel Exposure (Diesel Miners Only)

Full Model	Restricted Model	Variables Tested for Additional Explanation
Age	Age	
Height	Height	
Weight	Weight	
Smoking Status	Smoking Status	
Cum Diesel Exp1*		Cum Diesel Exp1
Cum Diesel Exp2		Cum Diesel Exp2
Y-Intercept	Y-Intercept	

	Log-Likelihoods by Symptom and Geographic Location: Full Model	Restricted Model	Additional Explanation
Cough			
Western	-63.071	-64.443	x^2 = 2.75, NS (2 df)
Eastern	-31.090	-31.498	x^2 = 0.82, NS (2 df)
Phlegm			
Western	-78.287	-79.160	x^2 = 1.74, NS (2 df)
Eastern	-38.151	-38.302	x^2 = 0.30, NS (2 df)
Breathlessness			
Western	-45.218	-45.458	x^2 = 0.48, NS (2 df)
Eastern	-25.927	-26.662	x^2 = 1.47, NS (2 df)

* Cumulative years of diesel exposure is entered in the logistic analysis using 2 binary-coded variables to code the three exposure categories.

the same population were phlegm, wheezing, and chronic stuffy nose.[26] No spirometrically measured pulmonary function changes with diesel use were found in the bus garage workers.[26] It should be noted that the bus garage workers experienced a higher level of diesel contaminants than our underground coal miners.[27]

The lack of association between diesel exposure and respiratory effects found in this study is generally consistent with the results of studies in other mining environments, with Weisenberger's review of diesel health effects,[28] and with an Environmental Protection Agency (EPA) summary of diesel effects on the respiratory system (although some of the EPA relationships were based on animal rather than human data).[6] Our findings of no relationship between diesel exposure and respiratory symptoms are inconsistent with those for bus garage workers, who were exposed to a higher level of diesel contaminants.

To date, only one study has reported cancer outcomes among workers exposed to diesel exhaust. That study reported lung cancer mortality among railway workers;[29] however, neither cigarette smoking nor job tenure was controlled in the analysis.

Limitations of the study. Epidemiological assessment of the chronic respiratory effects of underground exposure to diesel exhaust emissions has proven to be difficult. The 5-yr observation period used in this study may not have been a sufficient length of time for chronic respiratory effects to be observed. Measurement bias in pulmonary function, frequently a constant bias due to coaching, equipment, and other factors, may affect longitudinal analyses to a greater extent than it affects cross-sectional comparisons. Time-based pulmonary function changes are age-dependent; while every subject aged 5 yr, there is still the possibility of differential impact by aging. The measurement of chronic respiratory symptoms, subject to error due to the subjective nature of the reporting, is also subject to other influences, such as cigarette smoking, which may be measured imperfectly. Finally, comparison studies, performed upon the assumption that all other factors are equal, are flawed when these assumptions are not met. In the case of comparisons of coal miners from diesel-powered mines with miners from nondiesel-powered mines, all other factors are probably not equal. As has been mentioned, diesel-powered mines are frequently non-union, may employ a younger workforce, and may differ in other regards as well. For all these reasons, our results should be interpreted with caution.

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Intoxication by Cyanide in Fires: A Study in Monkeys using Polyacrylonitrile

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ABSTRACT. It is suspected that hydrogen cyanide (HCN) may be an important factor in incapacitating fire victims, but the effects of sublethal exposures are not well characterized. Also, the incapacitating effects of fire atmospheres result from exposure to a mixture of toxic products so that the contribution from each component is difficult to determine. The mechanisms of incapacitation in monkeys exposed to the pyrolysis products of polyacrylonitrile (PAN) were compared to those resulting from low level HCN gas exposures. The physiological effects of the PAN atmospheres were almost identical to those of HCN gas alone. They consisted of hyperventilation, followed by loss of consciousness after 1-5 min, bradycardia with arrhythmias and T-wave abnormalities, and were followed by a rapid recovery after exposure. Hydrogen cyanide is considered to be the major toxic product formed by the pyrolysis of PAN. It is suggested that HCN may produce rapid incapacitation at low blood levels of cyanide in fires, while death may occur later due to carbon monoxide poisoning or other factors.

HYDROGEN CYANIDE (HCN) is known to be produced in fires involving nitrogen-containing polymers[1,2] and is probably the most important narcotic fire product other than carbon monoxide (CO). In a recent pathological study of fire victims in the Strathclyde region of Scotland, elevated blood cyanide levels were found in 78% of fatalities, and 31% had blood levels considered to be toxic.[3]

Although the lethal effects of cyanide in man are well known, there is little information on the time course and severity of incapacitation produced during the early stages of exposures to sublethal concentrations of HCN which might impede escape from fires.

Another difficulty in predicting the incapacitating effects of fire atmospheres is that the thermal decomposition products from even a single material usually contain a mixture of chemical substances, and the composition of this mixture can vary considerably when the material is decomposed under different conditions of temperature and degrees of oxygenation.[1] In the Strathclyde study, high concentrations of cyanide in the blood of fire victims were usually associated with lethal