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COAL MINERS EXPOSED TO DIESEL EXHAUST EMISSIONS

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Abstract— The possibility of adverse respiratory health effects amongst coal miners in and at diesel-use mines has been investigated. Coal miners working in and at non-diesel-use mines served as matched controls. Differences in symptom prevalence and pulmonary function performance are documented. Several health indices have been related to a measure of diesel exposure. A preliminary characterization of the underground environment is shown. Underground miners in diesel-use mines reported more symptoms of cough and phlegm and had generally lower pulmonary function performance than matched controls. Similar trends were noted for surface workers at diesel-use mines compared with matched controls. Although a pattern consistent with small airways disease is shown, factors other than diesel exposure may be responsible. Exposure time to diesel emissions for miners in this study is relatively short and measured concentrations are low. Based on present information, sufficient and consistent evidence does not exist allowing for the rejection of hypotheses of health equality between matched groups. A prudent public health stance dictates reservation of judgment pending prospective examinations and detailed environmental surveys.

INTRODUCTION

HERETOFORE, respiratory effects amongst coal miners have been described and investigated largely in conjunction with exposure to coal mine dust. Various relationships involving exposure to respirable dust and the development of coal workers' pneumoconiosis have been quantified (JACOBSEN *et al.*, 1971; JACOBSEN, 1978; REISNER, 1971). The role of smoking on dose–response relationships has been documented (JACOBSEN *et al.*, 1977). REISNER (1971) studied the residence effect of dust in the lung, and the effect of quartz on the development of pneumoconiosis has also been investigated (WALTON *et al.*, 1977; JACOBSEN, 1978).

COCHRANE and HIGGINS (1961) and MORGAN *et al.* (1974) indicated that simple coalworkers' pneumoconiosis *per se* is not consistently related to reductions in ventilatory capacity; the prevalence of chronic obstructive airways disease is roughly equivalent in miners without pneumoconiosis. However, it has been shown that progressive massive fibrosis is related to significant decreases in ventilatory capacity and is associated with pulmonary impairment and premature death (COCHRANE *et al.*, 1964; ORTMEYER *et al.*, 1974; MORGAN *et al.*, 1972). Further, the probability of developing massive fibrosis is greatly increased once category two simple coalworkers' pneumoconiosis has developed (COCHRANE, 1962; MCLINTOCK *et al.*, 1971).

Geographic region appears associated with differences in ventilatory capacity and it has been suggested that the type of coal mined, the ethnic origin of the miners and other non-occupational factors might be responsible (MORGAN *et al.*, 1974). Some studies have shown that coal miners have more symptoms of persistent cough and phlegm and more ventilatory impairment than non-miner groups (HIGGINS and OLDHAM, 1962; ENTERLINE, 1967). There is also evidence that severity of bronchitic symptoms is associated with reductions in lung function greater than expected from the effects of dust, smoking status, age, and physical characteristics (ROGAN et al., 1973; HANKINSON et al., 1977). Several mortality studies of coal miners point to increased death rates due to respiratory conditions (JACOBSEN, 1976; ROCKETTE, 1977; ENTERLINE, 1964, 1967). The latter referenced works and studies by STOCKS (1962) give indications of increased mortality rates from other than respiratory conditions, such as carcinoma of the stomach. Overall standard mortality ratios, however, have often not deviated significantly from 100 (COCHRANE, 1973; LIDDELL, 1973; ORTMEYER et al., 1973).

Although the literature relating to the health of coal miners is voluminous, only two studies (REGER, 1978; REGER and HANCOCK, 1980) exist on the respiratory health effects amongst coal miners exposed to diesel emissions. Accordingly, the purpose of this study was to partially fill this vacuum. Four related research topics have been investigated: (1) differences in respiratory symptoms between diesel exposed and control miners, (2) differences in pulmonary function between diesel exposed and control miners, (3) between-group differences in respiratory symptoms and pulmonary function relative to an index of diesel exposure, (4) documentation of diesel engine emissions found in the underground mine atmosphere.

METHODOLOGY

Six coal mines utilizing diesel units underground were included in this study. Three were located in Utah and one each in Wyoming, Colorado and Kentucky. Four mines used diesel-powered units for face haulage of coal in place of conventional electric shuttle cars. Diesel front end scoops (for mucking operations) were also present at the four operations. Another mine used diesel-powered dump trucks for haulage of coal between the face and the tipple. One mine routinely used diesel units for mantrips and supply haulage.

All miners at the six operations were invited for examination. Nearly 1000 were examined and the participation rate was 93%. Each examination included posterior–anterior and left lateral chest films, a minimum of five spirometric manoeuvres, the administration of a modified version of the MRC respiratory symptom questionnaire (MRC COMMITTEE, 1960), an employment and smoking history, and the determination of selected demographic characteristics.

A dry rolling sealed spirometer was used for lung function testing. Flow volume curves of forced vital capacity manoeuvres were recorded on an FM analog tape and later processed on a digital computer. During testing, each curve was displayed on an oscilloscope for evaluation of reproducibility (HANKINSON and ROSE, 1974). Pulmonary function indices derived were the forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1) and flow rates at 5% intervals of the FVC exhaled. The primary measurements chosen for analysis were the FVC, FEV_1 and flow rate at 50% of the FVC (FEF_{50}). Peak expiratory flow and flow rates at 25, 75, and 90% were also considered. In the absence of total lung capacity (TLC), flow rates were not directly corrected for lung volumes; this was partially achieved through case matching procedures. The curve with the largest FVC and a peak flow within 15% of the maximum observed peak flow was chosen as the best curve. Flow rates were obtained from this 'best curve' determination. Volumetric measurements, *viz.* FVC and FEV_1, were taken as the maximum value, regardless of the curve on which they occurred.

Persistent cough was defined by a positive answer to: 'Do you usually cough first thing in the morning in the winter' or 'Do you usually cough during the day in the winter', plus a positive answer to: 'Do you cough like this on most days for as much as 3 months each year?' Persistent phlegm production was defined similarly. Moderate to severe shortness of breath was indicated by a positive answer to: 'Do you get short of breath walking with other people of your own age on level ground?'

The radiological classification of coalworkers' pneumoconiosis was based on the median of independent assessments from three 'B' readers using the 1971 ILO U/C standards (Jacobson and Lainhart, 1972).

Coal miners, at nearby mines, not exposed to diesel emissions were selected as the comparison group. The control subjects were examined in the National Study of Coalworkers' Pneumoconiosis, details of which are published elsewhere (Morgan *et al.*, 1973). Several criteria, on a man-by-man basis, were employed in matching control to diesel exposed miners. Geographic area, smoking status, and race were important considerations and matches achieved on these factors were undeviating. Three other variables were considered in the matching procedure: age, height and years spent in underground mining. Although exact matching was attempted on these factors, it could not be achieved and variance was allowed. Table 1 shows distributions relating to matching for age, height, and years spent in underground mining. Cases which could not be matched within reasonable limits were excluded. Women miners, office workers and others not specifically performing mining jobs were also excluded. Hence, data from 823 pairs of miners were available for analysis. Table 2 portrays the general precision achieved in the matching process. To a large degree, effects from extraneous variables which could bias the results were neutralized. Means and percentages for (matching) variables are roughly equivalent.

The analysis was dichotomized to insure a distinct separation between matched pairs of underground and surface workers. As such, two types of controls could be exercised. The first involved the matching of underground workers in such a manner that effects might be attributed to differences in exposure. The second and equally

Table 1. Closeness of matching* (diesel exposed minus controls)

Deviation units (D–C)	Height (in.) No.	Height (in.) (%)	Age (yrs) No.	Age (yrs) (%)	Mining experience (yrs underground) No.	Mining experience (yrs underground) (%)
< −3	19	2.3	24	2.9	4	0.5
−3	34	4.1	32	3.9	34	4.1
−2	58	7.0	50	6.1	67	8.1
−1	148	18.0	156	19.0	165	20.0
Exact	287	34.9	302	36.7	369	44.8
1	179	21.8	163	19.8	135	16.4
2	57	6.9	43	5.2	25	3.0
3	27	3.3	34	4.1	21	2.6
>3	14	1.7	19	2.3	3	0.4
Total	823	100.0	823	100.0	823	100.0

* Matching qualitatively exact (all cases) for race, region and smoking status.

TABLE 2. ANCILLARY VARIABLES FOR MATCHED PAIRS OF MINERS

Variable		Underground workers ($n=550$) Mean or (%)	S.D.	Surface workers ($n=273$) Mean or (%)	S.D.
Age	C	31.7	9.6	32.0	10.2
(yrs)	D	31.7	9.4	32.1	10.2
Height	C	68.8	2.4	68.9	2.6
(in.)	D	68.8	2.7	68.9	2.6
Time mining	C	4.7	5.6	1.1	1.9
(yrs underground)	D	4.7	4.2	0.6	1.8
Race	C	100.0		100.0	
(% white)	D	100.0		100.0	
Geographic area	C	60.6		54.9	
(% west)	D	60.6		54.9	
Smoking status	C	52.0		52.7	
(% smokers)	D	52.0		52.7	
Pack yrs of	C	11.6	10.7	12.0	11.9
cigarette smoking	D	13.4	13.1	16.2	15.8
(current and ex-smokers)					

C = Workers at non-diesel control mines.
D = Workers in or at diesel use mines.

important control involves disparities seen between matched surface workers, where no effect due to diesel exposure is expected. Therefore, checks in effects from one matched group to another could be made to partially quantify non-sampling error and other non-occupational factors.

A sample of miners at the diesel-use mines was asked to wear a personal dust sampler. The unit was operated at a flow rate of 2 l. min^{-1}, such that it would perform similarly to the human respiratory system with respect to deposition and retention of different sized particles (LIPPMANN, 1970). In addition, each subject was asked to wear tandem passive dosimeters (PALMES *et al.*, 1976) to measure concentrations of nitrogen dioxide. Area environmental measurements were also obtained to ascertain levels of CO, CO_2, NO_x, NO_2, SO_2, CH_2O and respirable and total dust.

Statistical procedures utilized and miscellaneous notes are contained in the Appendix.

RESULTS

Symptoms

Significantly more underground miners exposed to diesel emissions reported persistent cough than was the case with their matched controls: 23.6 vs 16.5%. Likewise, surface miners working at diesel-use mines reported more persistent cough than their matched counterparts: 20.1 vs 17.6%. These data are shown in Fig. 1(a).

Figure 1(b) shows that more of the underground diesel-exposed miners reported persistent phlegm production than their matched controls: 26.5 vs 22.8%. Amongst

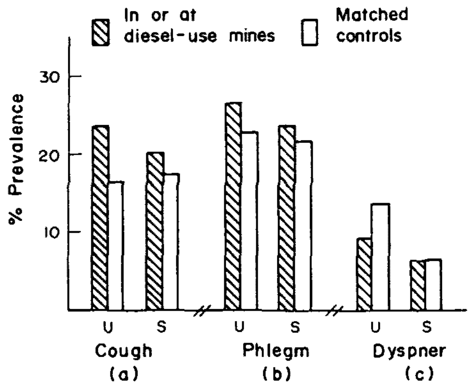

FIG. 1. Prevalence of persistent cough, persistent phlegm production and of moderate/severe dyspnea in or at diesel-use mines as compared with matched controls. U = underground workers, S = surface workers.

surface workers at diesel-use mines and their matches, the direction of the disparity was the same: 23.6 vs 21.8%.

The prevalence of moderate and severe dyspnea for workers in and at diesel-use mines and their matches is shown in Fig. 1(c). Directional differences are opposite those shown for cough and phlegm. This is especially so for underground matched pairs where a significantly higher proportion of the controls reported the symptom: 23.8 vs 9.3%. Amongst surface workers, equivalence in reported prevalence existed between matched pairs: 6.3 and 6.6%.

Figure 2(a) shows the reported prevalence of other selected symptoms for underground workers in diesel-use mines and their matched pairs. A significantly greater proportion of workers in diesel-use mines reported exacerbations of cough and phlegm than did their matched counterparts: 21.7 vs 16.2%. Between-group differences for wheezing, hemoptysis, nasal drainage and chest illnesses causing activity limitations were slight and non-significant.

Similar data for surface workers at diesel-use mines and their matches are shown in Fig. 2(b). No directional trends are evident and all between-group disparities are non-significant.

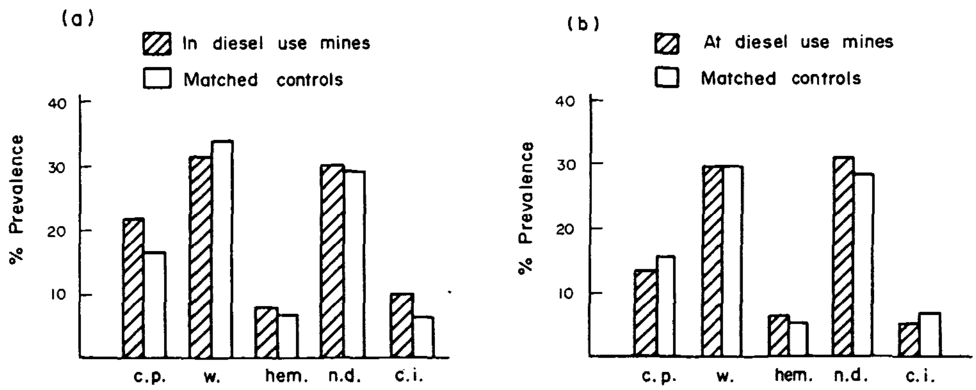

FIG. 2. Prevalence of selected symptoms: (a) underground workers, (b) surface workers, c.p. exacerbation of cough and phlegm; w wheezing; hem hemoptysis; n.d. persistent nasal drainage; c.i. chest illness which limits activity.

Pulmonary function

Figure 3(a) shows mean differences in several lung function parameters between underground workers exposed to diesel emissions and their matched controls. Significant decrements were evident for FVC, FEV_1, FEF_{75} and FEF_{90}, showing the diesel exposed individuals as having somewhat lower pulmonary performance than their matched controls. A marked reversal exists for peak flow, wherein the diesel-exposed workers showed a significant increase relative to their matched pairs.

The same directional phenomena exist for the surface workers at diesel-use mines and their matched pairs. These data are shown in Fig. 3(b). For these contrasts,

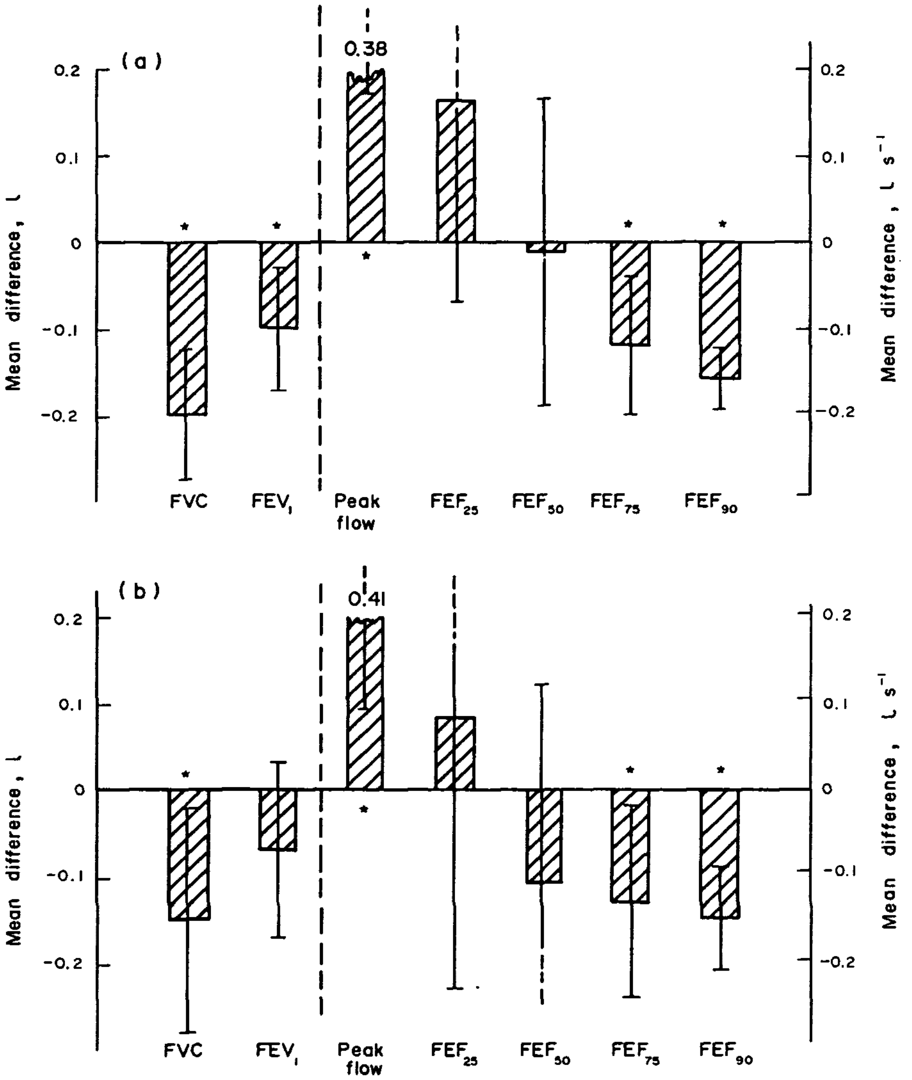

FIG. 3. Mean differences in pulmonary function (workers in or at diesel-use mines minus matched controls): (a) underground workers, (b) surface workers.
* Significantly different from zero ($P < 0.05$).

significant decrements were evident for FVC, FEF_{75} and FEF_{90}, showing the surface workers at diesel-use mines as having lower pulmonary function status than their matched counterparts. The surface workers at diesel-use mines also showed significantly elevated peak flows relative to controls.

The proportion of workers in or at diesel-use mines showing evidence of obstructive airways disease is equivalent to their matched controls. These data are shown in Table 3, *ca.* 12% of each group showing obstruction, the majority being of a mild form.

Although restrictive lung problems are not common amongst working miners (in the absence of PMF), some mild restrictive conditions were observed. These data are shown in Table 4. Roughly 4% of the underground workers in diesel-use mines showed mild restrictive lung problems, the corresponding prevalence for the matched controls being around 2%. An equivalent disparity exists between surface workers at diesel-use mines and their matched counterparts: 6 vs 3%.

Symptoms and pulmonary function related to diesel exposure index

Figure 4(a) shows differences in the prevalence of persistent cough by select subgroups of matched pairs. The pairs have been allocated to a particular exposure group depending on the tenure of time the diesel-exposed member spent underground. Surface workers and their matches are shown separately. A logistic fit to these data shows that an increase in the difference between the prevalence of persistent cough for subgroups does not coincide with an increase in the indirect exposure index. The

TABLE 3. PREVALENCE (%) OF OBSTRUCTION BY DEGREE OF SEVERITY*

Severity (FEV_1/FVC) (%)	Underground workers: In diesel use mines	Underground workers: In non-diesel use mines	Surface workers: At diesel use mines	Surface workers: At non-diesel use mines
None > 0.69	88.0	87.5	88.5	88.5
Mild 0.61–0.69	9.8	10.6	8.8	8.8
Moderate 0.45–0.60	2.0	1.8	2.7	2.3
Severe < 0.45	0.2	0.2	0.0	0.4

* Degree of severity from criteria contained in: Clinical Pulmonary Function Testing, Intermountain Thoracic Society, 1975.

TABLE 4. PREVALENCE (%) OF RESTRICTION BY DEGREE OF SEVERITY*

Severity FVC (% Predicted)	Underground workers: In diesel use mines	Underground workers: In non-diesel use mines	Surface workers: At diesel use mines	Surface workers: At non-diesel use mines
None > 0.80	95.9	98.0	94.2	96.5
Mild 0.66–0.80	4.1	1.8	5.8	3.1
Moderate 0.51–0.65	0.0	0.2	0.0	0.4
Severe < 0.51	0.0	0.0	0.0	0.0

* Degree of severity from criteria contained in: Clinical Pulmonary Function Testing, Intermountain Thoracic Society, 1975.

Predicted FVC from MORRIS *et al.* (1971): FVC = 0.148 height inches − 0.025 Age − 4.241.

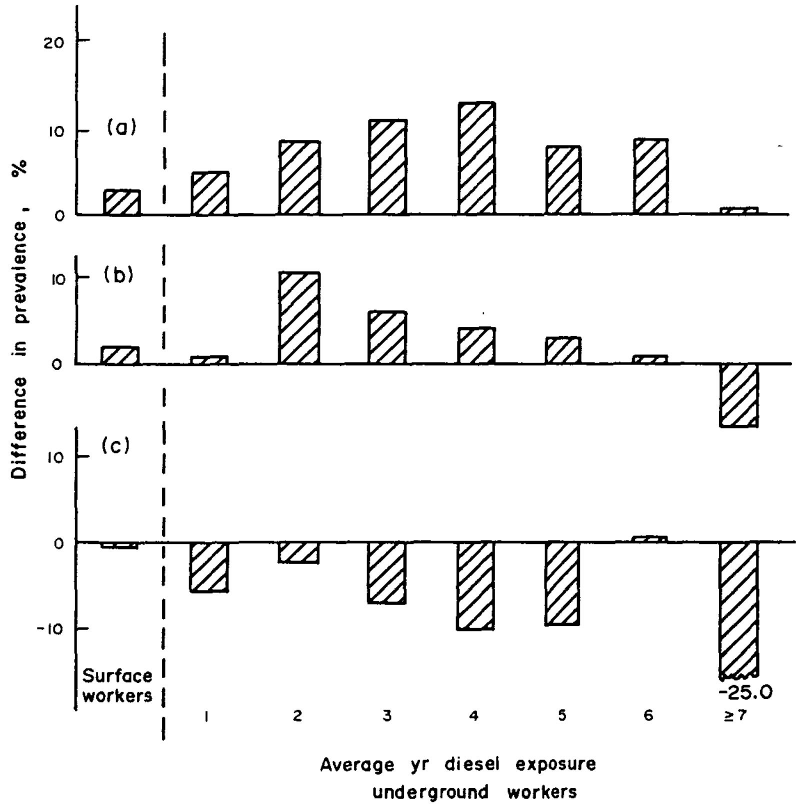

FIG. 4. Difference in prevalence of respiratory symptoms (diesel-exposed minus matched controls) vs yrs of exposure: (a) persistent cough, (b) persistent phlegm, (c) moderate/severe dyspnea.

relationship is nonsignificant and does not show an ever-widening departure from the zero line with increased exposure time.

Figure 4(b) shows similar data as it relates to persistent phlegm production. No consistent trend exists showing the difference in the prevalence of persistent phlegm for subgroups to be related to the indirect exposure index.

Differences in moderate to severe dyspnea by years of diesel exposure are shown in Fig. 4(c). A logistic fit to the data shows that the trend is not significantly different from the zero line.

Figure 5(a) shows mean difference in FEV_1 for matched subgroups by years of diesel exposure. As before, the years of diesel exposure relates only to that member of the pair who worked in an underground diesel-use mine. Each subgroup follows the overall trend in that the diesel-exposed individuals had (on average) a lower FEV_1 than their matched counterparts. However, a general linear model shows these data not departing significantly from zero.

Figure 5(b) shows the same type of information as it relates to the FVC by years of diesel exposure. The same pattern exists for FVC as with FEV_1, but even more so. The trend is more obviously parallel with the zero line. As the exposure index increases,

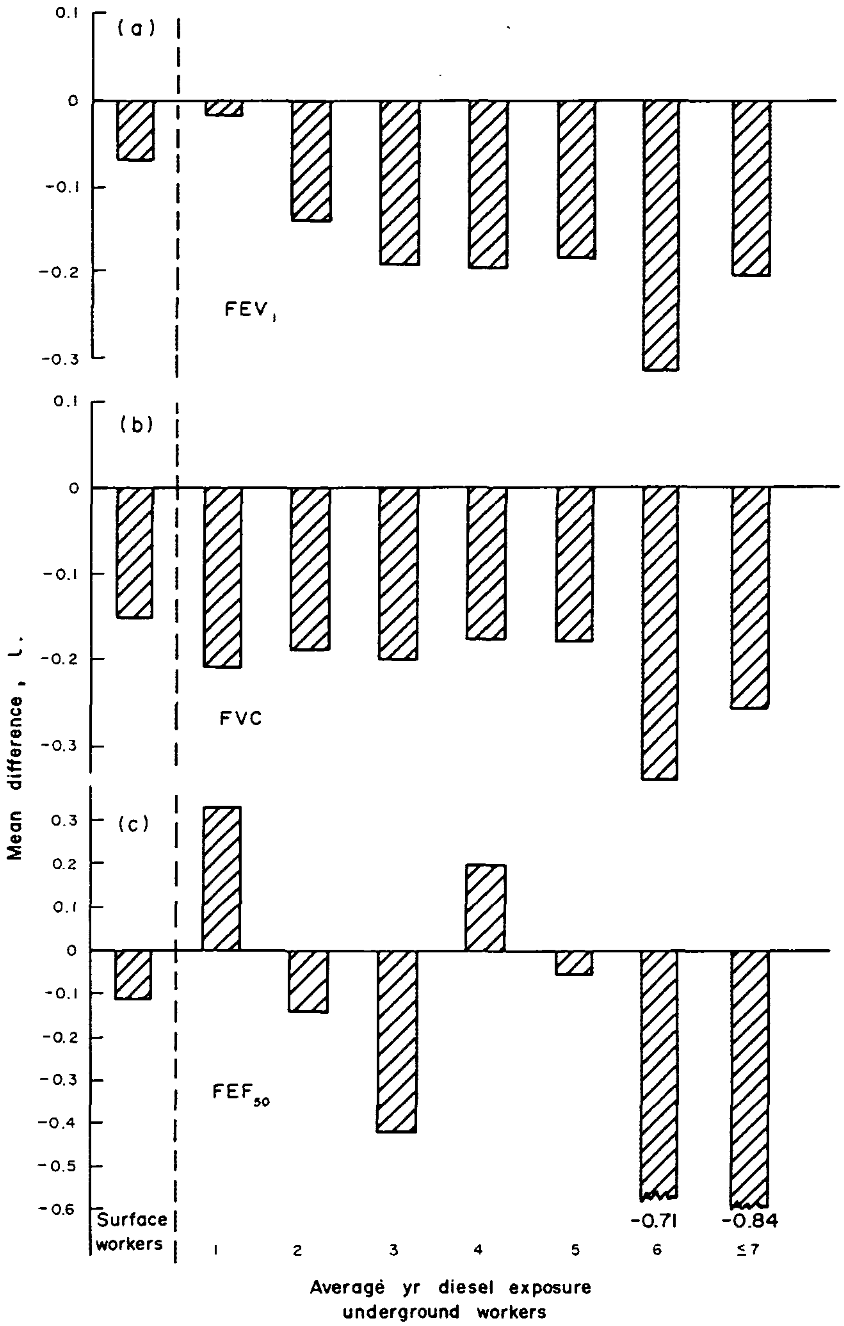

FIG. 5. Mean differences in lung function (diesel-exposed minus matched controls) vs yrs of exposure: (a) FEV$_1$, (b) FVC, (c) FEF$_{50}$.

there is no noticeable nor apparent widening of the discrepancy between the matched pairs of subgroups.

Figure 5(c) shows the mean difference in FEF_{50} by years of diesel exposure. An obvious lack of fit exists with these data and there is no noticeable trend of increasing or decreasing disparities between subgroups as the exposure index increases. The general linear model showed the relationship to be non-significant.

An analysis relating to degree of coalworkers' pneumoconiosis was considered but found to be unwarranted owing to the small number of cases involved. Only 4 cases of simple coalworkers' pneumoconiosis were found in each of the matched groups. No cases of progressive massive fibrosis were found. These data are shown in Table 5 for information only.

Potential interactions

Although not shown, the data were also analysed by age group, smoking status and mine, to ascertain if selected subgroups were contributing disproportionately to the overall differences. A fairly thorough mixing occurred between subgroups for each major factor considered. In short, there was no common thread indicating consistent interacting effects by particular subgroups.

Environmental measurements

Short-term detector tube samples were collected in work areas of the six mines. These data are shown in Table 6. Carbon monoxide (CO) levels ranged from slightly over 23 ppm in mine No. 5 to around 3 ppm in mine No. 1. Carbon dioxide (CO_2) levels ranged from trace detection upwards to 0.09% in mine No. 6. Oxides of nitrogen (NO_x) levels ranged from zero upward to 0.6 ppm in mine No. 1. Sulphur dioxide (SO_2) and formaldehyde (CH_2O) were either undetectable or found only in trace amounts.

In addition to detector tube samples, full shift personal samples (NO_2 and respirable dust) were collected from miners at each mine site. These data are shown in Table 7. The miners' personal exposure to NO_2 was relatively uniform between mines compared with the variability observed in short-term area samples. Full shift personal samples for NO_2 ranged from a high of 0.28 ppm in mine No. 2 to a low of 0.13 ppm in mine No. 6. Respirable dust levels as measured by the cyclone and filter method ranged from a high of 2.73 mg m^{-3} in mine No. 2 to a low of 0.93 mg m^{-3} in mine No. 1.

Passive dosimeters to measure NO_2 and pumps to measure respirable and total dust were situated at various stations within the mines. The range of these full shift area samples over all mines are reported in Table 8. As can easily be seen, maximum

TABLE 5. PREVALENCE (%) OF COALWORKERS' PNEUMOCONIOSIS

X-ray category	Workers in or at diesel use mines (%)	Workers in or at non-diesel use mines (%)
0	99.5	99.5
Simple	0.5	0.5
PMF	0.0	0.0
Total	100.0	100.0

TABLE 6. SHORT TERM AREA SAMPLES

Mine	CO (ppm) n	$\bar{X}$	S.D.	CO_2 (%) n	$\bar{X}$	S.D.	NO_x (ppm) n	$\bar{X}$	S.D.	NO_2 (ppm) n	$\bar{X}$	S.D.
1	12	3.4	3.4	8	0.07	0.02	12	4.3	2.8	12	0.6	0.6
2	9	21.3	12.6	9	0.06	0.02	10	5.2	5.3	8	0.1	0.2
3	7	8.3	1.5	6	0.07	0.03	7	2.0	1.1	6	0.0	
4	7	13.6	6.5	5	0.08	0.01	5	4.6	1.5	4	0.2	0.3
5	3	23.3	23.6	2	trace		2	0.0		2	0.0	
6	15	9.1	8.7	16	0.09	0.06	15	4.2	3.6	16	0.3	0.4

TABLE 7. FULL SHIFT PERSONAL SAMPLES

Mine	NO_2 (ppm) n	$\bar{X}$	S.D.	Respirable dust (mg m^{-3}) n	$\bar{X}$	S.D.
1	19	0.15	0.10	19	0.93	0.93
2	9	0.28	0.07	8	2.73	1.04
3	18	0.22	0.14	19	1.30	0.94
4	7	0.19	0.08	7	1.20	0.87
5	6	0.15	0.07	8	1.94	1.72
6	17	0.13	0.07	17	1.62	1.30

TABLE 8. FULL SHIFT AREA SAMPLES (RANGE OF OBSERVATIONS)

Area	NO_2 (ppm)	Respirable dust (mg m^{-3})	Total dust (mg m^{-3})
Intake	0.03–0.45	0.0–2.0	0.0–0.3
Haulage	0.05–0.80	0.4–4.6	0.6–14.7
Belt feeder	0.04–0.36	2.2–2.6	NA
Face	0.13–0.34	0.5–13.5	NA
Return	0.12–0.47	0.9–16.1	5.2–23.0

NA = Not available.

concentrations of NO_2 and respirable and total dust existed at the face and in the return airway.

COMMENT

REGER and HANCOCK (1980) reported preliminary results relating to chronic health effects of around 700 coal miners exposed to diesel emissions. Although there was a suggestion of adverse effects, the results were largely inconclusive owing to inadequate controls and the absence of environmental information. There is no other literature specific to the chronic health effects of coal miners exposed to diesel emissions. However, REGER (1978) investigated ventilatory function changes over a work shift of coal miners thus exposed. Decrements over a work shift existed for coal miners exposed to diesel emissions, but they were similar to changes shown for miners not exposed to diesel emissions.

Three recent reviews deserve comment. The proceedings of a workshop sponsored by the National Institute for Occupational Safety and Health (NIOSH, 1977) and a similar publication by ENVIRONMENTAL HEALTH ASSOCIATES (1978) considered the state of the art on health effects from diesel emissions in mines—and otherwise. Another review, completed by the U.S. ENVIRONMENTAL PROTECTION AGENCY (1978) involved possible health effects associated with emissions from light duty diesel engines. The major purpose of these reviews was to identify research deficiencies regarding health effects. In part, this study was an attempt to remedy one of the deficiencies noted.

KIBELSTIS (1975) reviewed the medical effects of diesel engines used underground. Effects relating to each exhaust component were discussed separately. Although synergistic effects were not considered, it was implied that adherence to recommended exposure limits would prevent significant impairment. STOKINGER (1975) reviewed the toxicology of diesel emissions and suggested that, of all diesel exhaust effluents, oxides of nitrogen posed the greatest threat to health. BATTIGELLI (1965) reported findings amongst railroad workers and volunteer subjects exposed to diesel exhaust. Neither respiratory complaints nor pulmonary function deficiencies could be related to exposure. Pulmonary resistance in the volunteer subjects exposed to pollution levels from diesel exhaust for short periods were similar to the results shown for railroad workers. JORGENSEN and SVENSSON (1970) reported spirometric results from over 200 iron ore miners working in a mine using diesel vehicles. They found no disparity between any groups studied other than what could be accounted for by age. ATTFIELD (1978) reported on the health status of nearly 5000 metal and non-metal miners exposed to varying concentrations of diesel emissions. He failed to show consistent trends in symptoms and lung function performance. From this investigation, ATTFIELD *et al.* (1982) studied a sub-group of potash miners exposed to diesel emissions. No consistent adverse effects associated with several indices of diesel exposure were shown, but caution was recommended in the interpretation of results. WALLER (1979) conducted a mortality study involving London transit workers, including garage workers exposed to diesel emissions in enclosed spaces. The death rates of cases experiencing mortality due to cancer of the respiratory system was no different from that shown for the general population of Greater London.

We have shown increased symptoms of cough and phlegm for underground workers in diesel-use mines as compared with matched controls. However, similar (but smaller) differences were found between surface workers at diesel-use mines and their controls—where there is no clear justification for attributing these latter changes to diesel exposure. We have shown that pulmonary function performance for the underground diesel-exposed workers was generally lower than their matched pairs. The same directional differences in pulmonary function were evident for the surface workers at diesel-use mines compared with their controls. Differences in selected symptoms between matched pairs relative to an index of exposure did not show trends consistent with an effect due to diesel emissions. Differences in pulmonary function performance between matched pairs for the same exposure index also failed to show trends consistent with a diesel-exposure effect. Obstructive airways disease (FEV_1/FVC ratio <0.70) was no more common amongst workers in or at diesel-use mines than with their matched counterparts. Disparities in symptoms and pulmonary function between matched groups could not be consistently attributed to select subgroups, i.e., involving smoking status, age group or mine. Preliminary industrial hygiene surveys at the diesel-use mines showed the components of diesel emissions measured to be low.

Although a summation of these data does not show clearly that diesel emissions are an added contributing factor to respiratory morbidity amongst coal miners, some of the reported results need further discussion.

The contribution of smoking to the prevalence of various symptoms is not consistent. In some instances, there was equivalence for current as well as non-smokers. There were, however, situations where current smokers reported the vast amount of the proportionate increase; in other cases, this was true for the non-smokers. Effects might be thought to show up more clearly amongst the non-smokers, as the effects of smoking would tend to mask the effects of exposure. This was not the case in this study. Although cases in this study were matched on the basis of smoking status, a secondary check was made on current and ex-smokers to insure that pack years of cigarette smoking were equivalent.

The increased prevalence of dyspnea amongst the control miners is not totally explicable. The possibility exists that the diesel-exposed miners who had shortness of breath selected themselves out of the population. On the other hand, the possibility also exists that the control miners (over the years) have been subjected to more information and testing procedures than the diesel-exposed group and, with knowledge regarding compensation benefits or transfer rights, may have the propensity to report more symptoms of breathlessness than diesel-exposed workers. Out-migration (in general) from the diesel-use mines is a factor which should be seriously considered. Aside from dyspnea, patterns suggestive of outward selection also exist when one scrutinizes the prevalence of cough and phlegm relative to exposure time.

The amount of time the matched groups spent in other dusty trades was considered as a confounding factor. This was of no consequence, as the control miners spent around $\frac{3}{4}$ of a yr in other dusty trades, whereas the diesel-exposed group spent around $\frac{1}{2}$ yr.

Pulmonary function performance is dependent to a large degree on coaching techniques. Slightly different technique and/or levels of coaching might have produced the pulmonary function disparities seen. This is a possible explanation, especially if the supposition of no difference in diesel exposure between matched pairs of surface workers is true. The workers in and at diesel-use mines had a lower FEV_1, higher peak flow and higher FEF_{25} than their matches. This pattern is indicative of better effort, at least in the initial phase of the manoeuvre. The reduced FVC is not so clearly explainable. One might hypothesize that end effort (for the diesel miners) was not optimum. However, this should result in elevated rather than depressed flow rates at low lung volumes. Clearly, this did not occur and, hence, the contention is not supported. The elevated peak flow of the workers in or at diesel-use mines seems inconsistent with the reported symptoms of cough and phlegm. Increased symptoms of cough and phlegm can be an indication of large airways disease. When this occurs, the peak flow is often decreased and one may also tend to see lower FEV_1/FVC ratios. Our data are not consistent with this pattern. We have reported symptoms consistent with large airways disease coupled with increased peak flow amongst the diesel-use miners; and their FEV_1/FVC ratios were roughly equivalent to matched controls. On the other hand, symptoms of persistent cough and phlegm may also occur with small airways disease, a possibility which must be considered in this study owing to the pulmonary performance of the diesel-exposed miners.

The diesel-exposed miners and their controls were examined at varying times during the year. There is no indication that more of one group than the other were examined during the summer or winter. Thus, it seems unlikely that season could account for the disparities in the prevalence of symptoms reported.

Another important factor considered was the respirable dust exposure for miners in each of the sample groups. Although the individuals in the groups were matched on the basis of tenure of underground experience, the possibility exists that the diesel-exposed miners might have had a higher (or lower) cumulative dust burden than the controls. Personal samples of respirable dust for each man examined in this survey were ascertained from compliance records. Samples were traced to the beginning of the sampling programme in 1970. On average, there was equivalence in the dust burden for the matched groups in this study. These data may be seen in Table 9.

TABLE 9. AVERAGE RESPIRABLE DUST BURDEN

Area worked	Type mine	mg m^{-3}
Underground workers	D	1.16
	C	1.02
Surface workers	D	0.84
	C	0.86

D = Diesel.
C = Control (non-diesel).

Preliminary industrial hygiene surveys at the diesel-use mines showed the levels of CO, CO_2, NO_x, NO_2 and respirable dust to be exceedingly low, well below legal or recommended standards. The miners' personal exposure to NO_2 was relatively uniform between mines compared with the variability observed from short term area samples. Since miners move through all sections of the mine, they move through areas of low concentration as well as stagnant areas where concentration build-ups occur. This tends to equalize the exposure to a relatively uniform dose. Respirable dust levels obviously vary among mines, primarily owing to type of ventilation and dust control methods employed. The highest average level observed was at mine No. 2. This result is unexpected, since these samples were collected during maintenance functions. All other mines were sampled on production shifts. The high values for this mine may be attributable to their use of a forced air ventilation system (fans and ventilation tubes) rather than directing section ventilation with brattice curtains. The range of values observed for working areas of a mine is sometimes greater than observed in the main return. This is due primarily to the imperfect mixing characteristics and non-uniform air flow patterns within the mine section. In the return, air flow rates are high and the flow pattern is turbulent, hence the air is well mixed. Measurements made in the returns are the best estimate for the section average to gaseous contaminants. Since most of the dust generated at the face is ventilated directly to the returns, this is not necessarily true for return air dust measurements. The respirable and total dust area samples were not collected in tandem, which accounts for the fact that the range of total dust measurements is not always greater than that measured for respirable dust.

Aside from the possibility of sample selection bias and interviewer and technician differences, there is the possibility that the surface workers at diesel-use mines were exposed to more diesel emissions than their matched counterparts. It was ascertained that surface workers at diesel-use mines rarely, if ever, go underground. Also, post survey industrial hygiene sampling (albeit crude) at a construction site with heavy diesel usage revealed NO_2 and NO_x as being non-detectable in the breathing zone of equipment operators. Although preliminary and indirect, this is particularly important in that proportionately more of the surface workers at diesel-use mines were heavy equipment operators, compared with their matches.

The differences occurring between surface workers and their controls was not a consequence of prior underground experience. Most surface workers had little to no underground tenure. The average tenure of underground work for the underground miners and their controls was only about 5 yr; on average, the prime interest group (underground workers in diesel mines) spent only 3 of those 5 yr underground in a diesel-use mine. Hence, insufficient time may have elapsed to determine a true effect.

SUMMARY

More underground workers exposed to diesel emissions reported symptoms of persistent cough and phlegm than did their matched counterparts. On the other hand, they reported proportionately fewer symptoms of moderate to severe dyspnea. On average, the underground workers at diesel-use mines showed a lower FVC, FEV_1 and flow rates at lower lung volumes (FEF_{50}, FEF_{75}, FEF_{90}) than their matched counterparts, while their peak flow and FEF_{25} was higher. Disparities in various health characteristics between workers in or at diesel-use mines and their matched controls related to an index of diesel exposure showed no significant trend. Health indicators for surface workers and their matches were directionally the same as for matched underground workers. If the assumption of no differences in exposure levels for matched surface workers holds true, then the phenomena thus observed rule out a clear-cut effect due to diesel emissions. The average respirable dust burden for the workers in or at diesel-use mines was roughly equivalent to their matched controls. Environmental samples taken at the diesel-use mines showed various components of diesel emissions to be exceedingly low, trace or non-detectable. On the basis of these data, one should reserve judgement pending maturation of the study group. Prospective examinations coupled with comprehensive environmental surveys are recommended.

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APPENDIX

Zeroing confounding variable effects by matching has both statistical and interpretive advantages. Between-group differences in age, smoking habits, height, race, region and tenure of employment can be reduced by case matching. Thus, a clearer view of environmental effects on the respiratory system might be obtained. Accordingly, a paired design was utilized. A paired analysis cannot, however, protect against bias in the data collection. In this study (and most epidemiological efforts) inherent difficulties in precisely carrying out the planned design and in data retrieval create potential for error. There was no interspersing of diesel and non-diesel miner examinations by either time sequence or collection site. These and other uncontrolled effects are thus likely to be unbalanced in the two groups. The combined effect of biases, however, are somewhat estimable if there are subgroups (surface workers in this study) within each sample whose exposures are similar. Assuming that within-region differences are slight and that the two surface environments do not effect the human respiratory system differently, then a comparison involving matched surface workers should serve well as an estimate of uncontrolled biases.

Analysis of epidemiological data should provide both a reasonable likelihood of detecting adverse health effects and protection from falsely condemning an environment as unhealthful. Protection from erroneous condemnation of diesel emissions was provided by selection of significance levels; in this study, the probability of this error was 5%. The likelihood of detecting symptom rate differences of 5% or more between matched underground miners, using a 5% significance level, was approx. 80%. The likelihood of detecting differences of 0.15 l. or greater in FEV_1 between matched underground workers at the same confidence level was approx. 99%. Paired comparison techniques (McNemar and paired t) were used for count and continuous data respectively. The data in this study were also analysed to determine if between-group differences in symptoms and lung function were associated with years spent working below ground in a diesel-use mine. An empirical logistic analysis was used for the categorical data (symptoms), while simple linear regression served to test relationships involving lung function performance.

Comparisons made in this study combined various age and smoking groups and testing sites. hence, the possibility of interacting effects between these groups could lead to erroneous conclusions. To insure this was not the case, the response variables were also examined by age categories, smoking status and by diesel mine. No formal tests for interactions between subgroups were applied. Visual inspection was adequate to insure that the combined analyses were not masking subgroup effects.