Leukemia Risk Among U.S. White Male Coal Miners

A Case-Control Study

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*The relevance of occupational exposure to electrical and magnetic fields (EMF) in the etiology of leukemia has been raised in several studies. Underground coal miners represent an occupational group with situationally determined EMF exposure, as high-voltage power distribution lines are strung overhead in the mines and converters and step-down transformers provide power to mining equipment. Risk in occupational exposure to EMF was examined in a case-control study of 40 leukemia decedents and 160 control subjects who died of causes other than cancer or accident and who were matched on age at death. The control subjects were selected from a group of 6,066 persons whose deaths were reported in four National Institute for Occupational Safety and Health cohort mortality follow-up studies. Based on these data, 25 or more years of underground mining, a surrogate of EMF exposure, was found to pose a statistically significant risk for leukemia (*International Classification of Diseases *[ICD] codes 204 through 207, eighth revision), myelogenous leukemia (*ICD *205), and chronic lymphocytic leukemia (CLL) (*ICD *204.1). Accumulative exposure to chemical agents probably poses a risk for acute myelogenous leukemia, although this relationship fell short of being statistically significant. Although CLL has not previously been attributed to environmental agents, these data suggest a possible CLL risk from prolonged exposure to EMF.*

The possible relevance of occupational exposure to electrical and magnetic fields (EMF) in the etiology of leukemia has been raised by Milham,[1] Wright et al,[2] McDowall,[3] and Coleman et al.[4] These studies have resulted in contradictory results ranging from an excess risk of leukemia to no excess risk. Similar contradictory results were reported for specific subgroups of workers and subtypes of leukemia. Where the subtype of leukemia was specified, it was reported only as acute leukemia, or as acute myelogenous leukemia (AML). In all studies, the numbers were relatively small and controls were drawn from groups at large or from general population statistics. In addition, only relatively broad measures of exposure were used.

Epidemiologic evidence of nonoccupational EMF exposure predicting childhood leukemia was presented by Wertheimer and Leeper[5] and Fulton et al,[6] also with contradictory results. These occupational and nonoccupational studies precipitated an editorial that emphasized study deficiencies and urged clearer delineation of any increased risk and better definition of etiology.[7]

Underground coal miners have a potentially significant occupational exposure to EMF. Power distribution lines are strung overhead in mines. Step-down transformers and converters provide 600 to 2,000 V to the mining equipment. Electrically operated trolleys are used for transportation of men and materials. While published figures on magnetic field exposures in underground coal mines[8,9] show the present levels to be low compared with aboveground measurements in residential areas,[10] actual measurements of electrical fields have not been taken in underground coal mines. However, close proximity of workers to step-down transformers and high-voltage lines can be observed. Given the coal miners' situationally determined EMF exposure to both electrical and magnetic fields, as well as the controversy concerning leukemogenic potential for EMF, the authors decided to analyze available National Institute for Occupational Safety and Health (NIOSH) evidence in a case-control study.

Methods

Forty coal miners who died of leukemia (*International Classification of Diseases [ICD]* codes 204 through 207,

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eighth revision[11]) were identified after review of 6,066 death certificates obtained from a population of approximately 19,000 coal miners originally entered in four NIOSH cohorts. The length of mortality follow-up varied for the cohorts: five years for one cohort; 10 years for another; 15 years for the third; and the fourth was an autopsy cohort. Causes of death were coded from death certificates by Public Health Service nosologists.

Each of the 40 white male leukemia patients was matched by age at death and year of birth (±3 years) to four control subjects from the same cohort who died of causes other than cancer or accident.

Number of years of underground mining employment at the time of cohort creation, divided at less than 25 years and 25 years and over, was used as a surrogate for exposure to EMF, although it is acknowledged that it is a generalized measure of mining exposure. Cigarette smoking and occupational histories were collected by questionnaire from the miners at the time the cohorts were established. Smoking status was reported in the following categories: current smoker, ex-smoker, and nonsmoker. Extensive coal dust deposition in the lungs, measured radiologically, defines coal workers' pneumoconiosis.[12]

Risk estimates are provided from calculations of odds ratios[13] (ORs) measuring the disproportionate exposure to EMF among the leukemia patients as compared with age-matched controls who died of causes other than cancer or accident. Statistical significance for either excess risk or protective risk is indicated using χ^2 or Fisher's exact test.[14]

Odds Ratios for Leukemia Risk by Years of Underground Coal Mining: 40 Cases and 160 Control Subjects Matched on Age at Death

Type of Leukemia	Odds Ratios*	No. of Cases
All leukemia (*ICD* 204-207)†	2.53‡	40
Underground 25+ yr		32
Underground < 25 yr		8
Acute leukemia (*IDC* 204.0, 205.0, 206.0, 207.0)	2.85	22
Chronic Leukemia (*ICD* 204.1, 205.1, 206.1, 207.1)	8.22‡	14
Lymphocytic leukemia (*ICD* 204)	2.32	14
Acute	0.63	2
Chronic	6.33‡	11
Not otherwise specified	NA	1
Myelogenous leukemia (*ICD* 205)	4.74‡	17
Acute	3.80	14
Chronic	NA	3
Other leukemia (*ICD* 206-207)	1.27	9

* Odds ratios for the risk of leukemia are defined by the ratio of miners with leukemia who have greater than 25 years underground to miners without leukemia who have greater than 25 years underground divided by the ratio of miners with leukemia who have less than 25 years underground to miners without leukemia who have less than 25 years underground (NA indicates not ascertainable)

† Eighth revision, *International Classification of Diseases*.

‡ $p < .05$, χ^2 test or Fisher's exact test

Results

Twenty-five years or more of underground coal mining employment, used as a surrogate measure of EMF exposure, was found to present a statistically significant risk for all leukemia (*ICD* codes 204 through 207; OR = 2.53, $p < .05$), chronic leukemia (OR = 8.22, $p < .05$), myelogenous leukemia (OR = 4.74, $p < .05$), and chronic lymphocytic leukemia (CLL) (OR = 6.33, $p < .05$) (Table). The increased risk observed for "all leukemia" cannot be related to cigarette smoking (OR = 1.02, not significant, data not presented) or to coal workers' pneumoconiosis (OR = 0.15, not significant, data not presented).

Discussion

Coal miners in general are not at increased risk for cancer, or more specifically for leukemia.[15] However, this case-control study clearly shows a 2½-fold increase in leukemia risk among coal miners who have worked underground for 25 or more years compared with those who have worked underground for less than 25 years. This leukemia risk associated with prolonged underground mining could be related to exposure to EMF,[16] to chemicals such as benzene,[17] or to other unrecognized agents, as the exposure index is nonspecific. Although AML has previously been related to chemical exposures,[17] the relationship of exposure to AML in this study falls short of reaching statistical significance. However, the risk for CLL is found to be elevated significantly (OR = 6.33) and CLL has been reported not to be related to chemical, radiation, or other environmental agents by most authors,[18-21] with a possible exception.[22] One previous report on electrical workers[4] suggest a slight increase in risk for CLL in electrical assemblers. Also, an unpublished NIOSH study of naval shipyard workers shows an increased leukemia risk among electricians that was specified only as lymphocytic leukemia (F. Stern, M.S., personal communication, 1983). A possible biological mechanism relating agents such as EMF to alterations in the immune system, thus causing predisposition to CLL, may be inferred from animal studies.[23-25] Matanoski et al[26] hypothesize that cumulative low-dose (gamma) radiation alters the immune system, leading to an increased incidence of chronic diseases and lymphomas among radiologists.

Conclusions

An increased risk of leukemia associated with prolonged underground mining exposure has been shown in a sample of U.S. white male underground coal miners. Multiple exposures in the coal workers' environment could be predisposing factors. Exposure to benzene in degreasing operations commonly employed in coal mines until the mid-1970s could explain the slightly elevated risk for AML. The increased risk for CLL is possibly due to other factors since, to date, no risk for CLL from environmental agents has been proven. Given the recent suggestions of a relationship between EMF exposure and chronic leukemia, electromagnetic radiation is a prime suspect in the elevated risk for CLL.

In summary, the authors propose that the etiology for an increased risk for leukemia among coal miners employed underground for 25 or more years is possibly twofold: (1) accumulative exposure to chemical agent(s) and

(2) exposure to electromagnetic fields, particularly electrical fields. The former exposure is possibly related to AML; the latter exposure is perhaps related to CLL.

Recommendations

Further studies must relate risk factors to specific subtypes of leukemia. To test the EMF exposure-leukemia risk hypothesis, which seems provocative in light of these findings, EMF dose documentation should measure both electrical and magnetic field strengths. Since mining methods are changing, present EMF measurements probably would not reflect historical exposures.

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Reconcilement with Reality

If the steps from infancy to childhood to adolescence lead in sequentially mastering our body, our reality, and our emotions, then from 40 to senescence the steps lead in the reverse direction. Thus, if the 40-year-old struggles with feelings, the 55-year-old struggles once more with reality. If bitterness is to be avoided, the promises and dreams of the 30s must be reviewed as nostalgia. Reality must replace the ideal, and we must accept that life's seesaw has tipped; that there are now more yesterdays than tomorrows.

— From *Adaptation to life* by George E. Vaillant, M.D. Published by Little, Brown and Company, Boston, 1977.