National Trends in Silicosis Mortality in the United States, 1981–2004

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Background *This article describes trends in mortality with silicosis and identifies industries and occupations with elevated silicosis mortality.*
Methods *A total of 6,326 deaths with silicosis for 1981–2004 were analyzed for trends and association with occupation and industry. Annual mortality rates were age-adjusted to the U.S. Year 2000 population. A linear regression model was used for analyzing mortality trends. Proportionate mortality ratios (PMRs) were based on 1,440 deaths with information on usual industry and occupation.*
Results *Overall age-adjusted mortality rates per million declined from 2.4 in 1981 to 0.7 in 2004. Industries having significantly elevated PMRs for silicosis included mining and quarrying. Occupations with elevated PMRs included those associated with metal and mineral processing.*
Conclusions *The results suggest that considerable progress has been made towards elimination of this preventable disease. However, about 30 silicosis deaths per year have been recorded since 1995 among those of working age, warranting continued efforts to effectively limit workplace exposures.* Am. J. Ind. Med. 51:633–639, 2008.
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KEY WORDS: silicosis; mortality; industry; occupation; proportionate mortality ratios

INTRODUCTION

Silicosis is an occupational lung disease caused by inhaling dust containing fine particles of crystalline. Crystalline silica is ubiquitous, occurring in native rock, stone, and sand, and in manufactured products containing these materials, such as concrete, bricks, and tiles. Excavating or working with materials that contain crystalline silica can produce airborne respirable dust, causing lung damage. Occupational exposures to respirable size silica dust occur in mining, quarrying, drilling, and tunneling operations. Silica exposure is also a hazard to sandblasters, stone blasters, stonecutters, and pottery, foundry, ground silica, and refractory brick workers [Beckett et al., 1997; Parker and Petsonk, 1998]. Silica sandblasting carries high risk for excessive exposure to silica even though respiratory protection is used [Bailey et al., 1974; Glindmeyer and Hammong, 1988; Fleming et al., 1990; Abraham and Wiesenfeld, 1997].

Silicosis has a long latency period of usually 10–30 years from the beginning of exposure to the recognition of radiographic manifestations. Accelerated silicosis appears radiographically as simple silicosis which develops after less than 10 years of excessive silica exposure [Weissman and Banks, 1998]. Silicosis has been recognized in rock drillers employed in caisson construction [Ng et al., 1987], metal mining [Ezenwa, 1982], tunnel construction [Bavley,

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1950; Burns et al., 1962; Cherniack, 1989], highway and dam constructions [Burns et al., 1962; Valiante et al., 2004], coal miners [Green et al., 1989; Kreiss and Zhen, 1996], slate quarries [Sacharov et al., 1971], and rock quarries [Ahlman et al., 1975; Guenel et al., 1989]. A recent study estimated that there were 3,600–7,300 silicosis cases in the United States (U.S.) from 1987–1996 [Rosenman et al., 2003]. The National Institute for Occupational Safety and Health (NIOSH) has reported 15,071 deaths with silicosis observed in the U.S. from 1968 to 1999 [NIOSH, 2003].

The purpose of this article is to present the national trends of silicosis mortality over time, the demographic and geographic distribution of silicosis deaths, and to identify occupations and industries with elevated proportionate mortality ratios for silicosis.

MATERIALS AND METHODS

The National Occupational Respiratory Mortality System (NORMS) was used to extract the information presented in this article and thereby identify geographic areas with greater silicosis mortality, as well as industries and occupations with elevated proportionate mortality ratios [NIOSH, 2004]. The Division of Respiratory Disease Studies, NIOSH, developed the NORMS using National Center for Health Statistics (NCHS) multiple-cause-of-death data available since 1968 and industry and occupation data available for 1985–1999 [NCHS, 2007].

The NORMS is an interactive data-retrieval system, permitting retrieval of death counts and rates by time period, geographic region, and industry and occupation, among other things. NORMS can be accessed from the NIOSH website [NIOSH, 2004]. The database contains data for both underlying, contributing, and multiple causes of death on work-related respiratory conditions such as pneumoconiosis (e.g., silicosis and asbestosis), respiratory tuberculosis, malignant mesothelioma, and other respiratory conditions as recorded from death certificates, as well as demographic information on all U.S. decedents.

In the NORMS, the International Classification of Diseases (ICD)-9 and ICD-10 codes were used to define silicosis: ICD-9 code (502) for the years 1981–1998 and ICD-10 code (J62) for the years 1999–2004 [USDHHS, 1988; WHO, 1992]. For this analysis, all decedents less than 15 years of age were excluded because of the occupational nature of silicosis. Multiple cause-of-death data were used to identify 6,326 deaths with silicosis during the 24-year period, 1981 through 2004. Mortality rates were age-adjusted to the 2000 U.S. population as the standard. A simple linear regression model was used for plotting trends in age-adjusted mortality rate for 24 years. The *t*-test was used to test significance of the slope in the regression model for silicosis mortality rates for the 24-year period [Armitage, 1973].

In the NORMS the usual occupation and industry listed on death certificates for the period 1985–1999 are coded using the 1990 Bureau of Census classified index of industries and occupations [USDCESA, 1992]. The proportionate mortality ratio (PMR) for silicosis was computed by occupational and industrial categories. The PMR was defined as the observed number of silicosis deaths with the specified usual occupation or industry divided by the expected number of silicosis deaths, adjusted by age, sex, and race [NIOSH, 2003]. Ninety-five percent confidence intervals of PMRs were calculated assuming Poisson distribution of the data [Bailar and Ederer, 1964]. A PMR was considered to be significantly elevated if the lower 95% confidence limit was greater than 1.0.

For mapping the geographic distribution of mortality by county, mortality rates per million per year were classified by three ranges: (1) rate >0–0.68, (2) rate >0.68–1.36, (3) >1.36–2.72, and (4) rate >2.72. Age-adjusted mortality rates for counties with 1–4 deaths were not calculated for confidentiality reasons.

RESULTS

Table I shows the demographic characteristics of decedents with silicosis by sex, race, and age group. The total deaths with silicosis from 1981 through 2004 was 6,326. Approximately 96% of deaths with silicosis occurred in males. The racial distribution of decedents with silicosis was approximately 85% white, 14% black, and less than 1% other race. Although the median age at death was 75, and the majority of deaths (81.3%) occurred in the 65 and older age groups; there were 1,184 decedents with mention of silicosis

TABLE I. Demographic Characteristics of Decedents With Silicosis by Sex, Race, and Age Group, United States,1981–2004

	Number of deaths	%
Total	6,326	100.0
Sex		
Male	6,100	96.4
Female	226	3.6
Race		
White	5,358	84.7
Black	917	14.5
Other	51	0.8
Age group		
15–24	6	0.1
25–34	19	0.3
35–44	95	1.5
45–54	239	3.8
55–64	825	13.0
65 and over	5,142	81.3

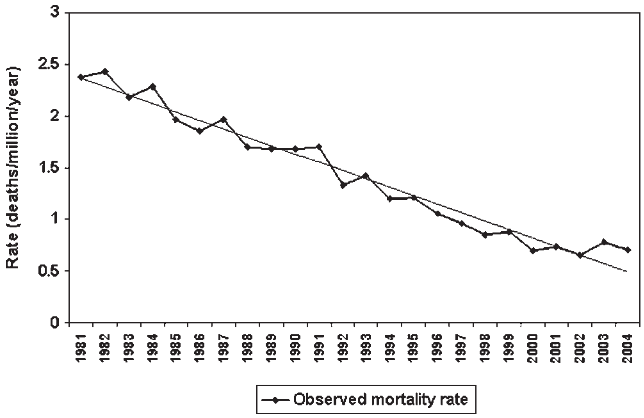

FIGURE 1. Trends of age-adjusted silicosis mortality rates, United States, 1981 – 2004. Line indicates linear mortality trend.

on the death certificate who were less than 65 years old during the period 1981–2004. There was 120 young deaths with silicosis among persons aged 15–44 years. Since 1995, an average of 30 deaths per year has been recorded in the 15- to 64-year-old group.

Figure 1 shows annual age-adjusted silicosis mortality rates (per million population) from 1981 to 2004. The rate declined by 70.6% from 2.4 in 1981 to 0.7 in 2004. A simple linear regression analysis indicated a negative correlation (r = −0.98) between annual age-adjusted rate and years from 1981 to 2004. The slope (−0.08 deaths per million per year) in the regression model was statistically significant ($P < 0.0001$).

Figure 2 presents the geographic distribution of age-adjusted silicosis mortality rate by county. The rates were greater in several counties in western states (e.g., California, Nevada, and Arizona), Gulf coastal states (e.g., Texas), northeastern states (e.g., Pennsylvania, Ohio, and West Virginia), and mid-Atlantic states (e.g., North Carolina). Mitchell County, North Carolina, had the greatest age-adjusted mortality rate (74.9), followed by White Pine County, Nevada (52.0).

A total of 1,400 deaths with silicosis was reported in 26 states having usual industry and occupation codes for one or more selected years.

Table II shows the top 10 usual industries with elevated PMRs. Among industries, *metal mining* had the greatest PMR (39.2, 95% CI = 32.9–46.8). Table III shows the top 10 usual occupations with elevated PMRs. Among occupations, *miscellaneous metal and plastic processing machine operator* had the greatest PMR (90.1, 95% CI = 51.5–146.3).

DISCUSSION

Silicosis mortality has clearly declined in the 24 years between 1981 and 2004. There are two main reasons for this trend. First, many of the deaths in the early part of the study period, that is, around 1981, were for individuals whose main exposure to crystalline silica dust probably occurred well before the introduction of national compliance limits for silica dust exposure. National compliance limits on silica

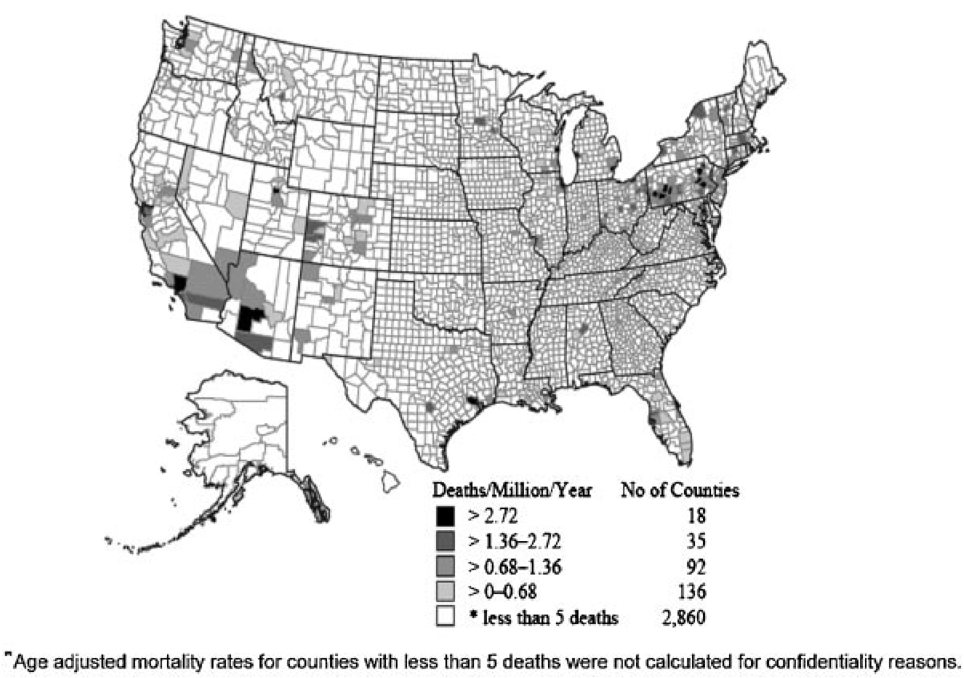

FIGURE 2. Geographic distribution of age-adjusted silicosis mortality rates by county, United States, 1981 – 2004.

TABLE II. Top Ten Usual Industries With Elevated PMRs, United States, 1985–1999

Census industry code	Industry	Number of deaths	PMR	95% confidence interval
040	Metal mining	128	39.2	32.9–46.8
262	Miscellaneous nonmetallic mineral and stone products	79	32.2	25.7–40.4
261	Pottery and related products	30	31.3	21.1–44.6
050	Nonmetallic mining and quarrying, except fuel	80	30.4	24.3–38.1
271	Iron and steel foundries	84	20.2	16.3–25.2
252	Structural clay products	30	16.9	11.4–24.2
041	Coal mining	101	5.6	4.6–6.9
300	Miscellaneous fabricated metal products	27	4.8	3.1–7.0
682	Miscellaneous retail stores	14	4.0	2.2–6.7
270	Blast furnaces, steelworks, rolling and finishing mills	91	3.4	2.8–4.2

dust began to be applied in the early 1970s and included indirect control through regulation of mixed mine dust in underground coal mines using the formula; (10 mg/m^3 MRE)/(%Quartz) [NIOSH, 1995], and direct control of crystalline silica as respirable quartz in general industry or metal mining using the formulas: (10 mg/m^3)/(%$SiO_2 + 2$) [USDOL, 2004]. These limits, together with recommendations such as that by NIOSH (that occupational exposures to respirable crystalline silica shall not exceed 0.05 mg/m^3 (time weighted average concentration), for up to 10 hr/day, during a 40-hr work week) [NIOSH, 1974, 1988], should have led to reduced silica dust exposures from about 1970 to the present. For example, a study on historical respirable quartz exposures of industrial sand workers for 1946–1996 reported that quartz concentration decreased over time, indicating significantly greater measurements (average100 mg/m^3) in the 1970s than those measured (below 10 mg/m^3) since 1990 [Sanderson et al., 2000]. It follows that those dying towards the end of the study period, that is, around 2004, would have worked at least part of their life in lower silica dust levels than did their older colleagues. Ancillary preventive measures, such as respiratory protection, posting of warning signs, and recordkeeping or reporting of occupational illnesses may also have acted to reduce personal exposures from the 1960s. In some instances, dust control preceded Occupational Safety and Health Administration (OSHA) controls. For example, exposure levels in the granite sheds decreased from 20 to 50 million particles per cubic foot (mppcf) to 3–5 mppcf in the 1950s and 1960s, after the Vermont granite industry started to control exposures in the 1940s [Corn, 1980]. Along with the imposition of dust limits and associated measures, a greater awareness of the risks of inhaling silica dust may have contributed to the reduction in mortality. The efforts of NIOSH and other organizations, including improved surveillance, identification of hazards, and dissemination of education materials, may have contributed to this.

The second major factor relates to employment in heavy industries (e.g., steelworks and foundries, where silica exposures were prevalent). These industries have been declining over the years. It is possible that part of the reduction in mortality evident during 1981–2004 is due to the fewer workers being exposed to silica dust over time. Because of the long latency associated with the development

TABLE III. Top Ten Usual Occupations With Elevated PMRs, United States, 1985–1999

Census occupation code	Occupation	Number of deaths	PMR	95% confidence interval
725	Miscellaneous metal and plastic processing machine operators	16	90.1	51.5–146.3
675	Hand molders and shapers, except jewelers	27	40.8	26.8–59.4
787	Hand molding, casting, and forming occupations	12	32,3	16.6–56.3
768	Crushing and grinding machine operators	29	30.8	20.7–44.2
719	Molding and casting machine operators	43	19.3	14.0–26.0
046	Mining engineers	5	16.4	5.3–38.2
616	Mining machine operators	208	12.1	10.6–13.9
617	Mining occupations, not elsewhere classified	12	11.2	5.8–19.6
613	Supervisors, extractive occupations	9	10.9	5.0–20.6
599	Construction trades, not elsewhere classified	16	7.5	4.3–12.1

of silicosis, the decrease in mortality is lagging behind these industrial changes.

Despite the reductions in mortality associated with silicosis, silica exposure remains ubiquitous. NIOSH estimated that 1.7 million workers were potentially exposed to crystalline silica dust [NIOSH, 1991]. A recent study estimated 121,100 workers exposed to equal or greater than the NIOSH recommended exposure limits in 1993 [Linch et al., 1998]. Furthermore, despite the existence of enforceable limits on worker exposure to respirable crystalline silica dust, substantial overexposures continue to occur in the U.S. For example, in 1983 a 34-year-old surface coalmine driller was reported to have silicosis. This person had operated a rotary drill using a dry drilling technique at a surface coalmine for 5 years [Banks et al., 1993]. In 1988, overexposure to silica dust was reported in Texas. Ten cases of silicosis were identified among workers who were employed in sandblasting oilfield drilling pipes. Personal air samples showed high respirable silica exposure level ranging from 400 to 700 $\mu g/m^3$ for workers in the sandblasting area [Fleming et al., 1990]. Ten years later, deaths from silicosis were reported in two men aged 30 and 36 years who also were sandblasters in Texas [NIOSH, 1998]. The same report showed that 1.4% of all silicosis deaths occurred in the 15- to 44-year age group during 1968–1994. In our study there were 120 young silicosis deaths (1.9% of 6,326 deaths) among persons aged 15–44 years. These findings indicate the critical need to educate workers and employers to the dangers of inhaling silica dust, and to ensure that enforcement and preventive measures are applied scrupulously. The suggestion in Figure 1 that the long-term downward trend in silicosis death rates may have ceased around 2000 supports renewed emphasis on education and enforcement.

The results of the PMR analysis presented in this report showed an elevated risk of silicosis in several industries and occupations. By industries, *metal mining* had the greatest PMR. Approximately 12% of the air samples for respirable silica dust collected by the Mine Safety and Health Administration (MSHA) on workers in the metral mining industry exceeded the permissible exposure limit (PEL) during the period 1990–1999 [NIOSH, 2003]. Underground mining for metals usually involves removal of respirable quartz-rich ores. Silicosis may be caused by mining metals such as iron, nickel, silver, and tungsten [Weissman and Banks, 1998]. Recent Sentinel Event Notification Systems for Occupational Risks (SENSOR) findings showed that 58% of reported cases of silicosis from Michigan, New Jersey, and Ohio worked in primary metal industries [NIOSH, 2003]. Additional industries with elevated PMRs were *miscellaneous nonmetallic and stone products* and *pottery and related products*. The pottery industry uses various silica-containing raw materials in the manufacturing of ceramic, sanitary ware and other types of pottery (Shy, 2000). In 1992, two cases of silicosis in former employees of a pottery plant in New Jersey were reported [CDC, 1992]. Occupations with elevated PMRs included those associated with metal and mining processing (e.g., casting, molding, crushing, and grinding), and mining (e.g., *mining machine operators*). The greater PMRs in these occupations are consistent with a previous report based on NCHS multiple-cause-of-death data from 1985–1990 [Bang et al., 1995].

The geographic patterns of silicosis offer some guidance for intervention. The top 10 states with the greatest number of silicosis deaths were Pennsylvania, Ohio, California, New York, Michigan, Wisconsin, Illinois, Colorado, Texas, and Florida. Silicosis deaths in these states accounted for 58% of total deaths for the study period. California has the highest estimated numbers of workers (approximately 150,000) with potential exposures to respirable crystalline silica dust [NIOSH, 1991]. By county, the greatest age-adjusted mortality rates were clustered in westerns states (e.g., California, Nevada, Utah), Gulf coastal states (e.g., Texas), northeastern states (e.g., Pennsylvania, Ohio, New Jersey, West Virginia, Michigan), and mid-Atlantic states (e.g., North Carolina). The mortality rates in these counties were often associated with mining or construction industries. For example, the high mortality rate in one county in South Dakota may be associated with gold mining in that area. A study of 3,328 gold miners exposed to silica in South Dakota reported significantly increased risk of silicosis [Steenland and Brown, 1995]. The elevated mortality rate that we reported in Lawrence County (Fig. 2) is mostly associated with gold mining. In Vermont, high mortality rate in one county is also likely associated with granite industry. The relationship between quantitative measures of exposure to silica dust and silicosis (and other diseases) among Vermont granite workers was clearly demonstrated in 2004 [Attfield and Costello, 2004]. The same analysis noted that pre-1940 airborne concentrations of respirable silica dust could have been as high as 1.07 mg/m^3 in some jobs.

Although the geographic mortality patterns by state and county may provide general surveillance information on silicosis deaths and thereby suggest possible interventions, the data do not necessarily indicate that the deaths in those locations were due to exposures in the same state or county. For example, Florida counties showing greater mortality rates may be simply due to migration of elderly individuals with silicosis to this state. Further investigation is needed to determine whether silicosis deaths in the counties with greater silicosis mortality rates on Figure 2 were truly associated with excessive silica exposure in the workplaces there.

A strength of the multiple-cause of death data used in this study is that they permit ascertainment of contributing, as well as underlying cause of death. This is important for chronic diseases like silicosis, which may cause years of impairment and disability in individuals who more often than not die as a result of another underlying cause. In our study, nearly 53% of the silicosis deaths ascertained from the multiple-cause-of-death data with silicosis were listed as a contributing cause.

There are several limitations that affect this study. First, the coded usual industry and occupation on death certificates may not accurately represent the source of the exposure that gave risk to silicosis. That is, the silica exposure may have been received when the individual's employment was not their *usual occupation or industry*. Moreover, the stated job or industry may not be specific enough for accurate identification of the circumstances of the exposure. Second, NCHS provides coding for usual industry and occupation only for the period 1985–1999 from 26 states. The resulting figures are not necessarily representative of the national situation. Third, geographical mortality patterns reflect by the long latency and retirement issues. Fourth, there may be some misclassification or under-reporting of silicosis deaths by physicians. Several studies have reported on the potential for misclassification of cause of death and validation of the death certificate diagnosis [Cina et al., 1999; Goraya et al., 2000; Rosenman et al., 2003]. In addition to potential missed diagnoses by physicians who care for patients with silicosis, the way in which underlying or contributing causes of death are written on the death certificate affects the coding of cause of death. For example, 10% of all pneumoconioses were recorded as type ''unspecified'' on the death certificate during the period 1990–1999 [NIOSH, 2003]. Inaccuracy in cause of death information can lead to underestimated counts due to false negatives (i.e., failing to detect true cases) [Rosenman et al., 2003]. A recent study of silicosis in the U.S. estimated 3,600–7,300 cases based on data from U.S. death certificates, the Michigan state-based surveillance system, and capture-recapture analysis [Rosenman et al., 2003].

In conclusion, the temporal silicosis mortality trends suggest that considerable progress has been made toward elimination of preventable silicosis. However, about 30 silicosis deaths yearly have been recorded since 1995 among those of working age (15–64), warranting continued efforts to effectively limit workplace exposure to crystalline silica for prevention of silicosis.

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