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Prevalence of Arthritis and Rheumatoid Arthritis in Coal Mining Counties of the U.S.

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Abstract

Objective: Exposure to inhaled mineral dust, in particular silica, is associated with increased odds of rheumatoid arthritis (RA) and other autoimmune diseases. We studied the association of RA with work-related coal and silica exposure in the Appalachian region of the U.S.

Materials and Methods: We carried out a random-digit-dial telephone survey in selected counties in Appalachia with elevated coal workers' pneumoconiosis mortality. We studied males, age ≥50, with any employment history, assessing exposure to coal mining employment, other work-related dusts, and ergonomic factors. We ascertained self-reported physician diagnosis of any arthritis and of RA with glucocorticoid treatment. We used multivariable logistic regression analysis to estimate the odds ratios (ORs) and associated population attributable fraction (PAF) estimates.

Results: Among the 973 men meeting study entry criteria (age 66±10 years; 54% ever smokers), 266 (27%) reported coal mining work and 189 (19%) reported other work-related silica exposure. There were 517 (53%) reporting any arthritis and 112 (12%) meeting the study definition of RA. Adjusting for covariates, coal mining was associated with elevated odds of RA (OR 3.6; 95% CI 2.1, 6.2) accounting for a PAF of 33% (95% CI 26, 40%) of the men studied. For any arthritis, the coal-associated OR was 2.3 (95% CI 1.6, 3.2) and the associated PAF 20% (95% CI 14, 25%).

Conclusions: In this population of older males living in a coal mining region, we estimated that 20% of arthritis and 33% of RA may be attributable to coal mining work.

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Rates of arthritis are elevated in states in the U.S. with large numbers of coal miners. Based on 2015 data, West Virginia has the highest prevalence of arthritis among adult males (32.8%, age adjusted) and one of the narrowest gender gaps (only 1.4% less than women) of any state in the U.S.[1] Further, Tennessee and Kentucky have the third and fourth leading state rates for arthritis among adult males (26.3% and 26.2%, respectively), while Pennsylvania and Ohio both have state rates for adult males for arthritis ranked 14 and 16 in the U. S. In comparison, the age-adjusted adult male arthritis prevalence rate in California, a state without many coal miners, is 15.7%. The cause of this geographic clustering is unknown, either for degenerative arthritis (the dominant form of the condition) or for inflammatory/autoimmune arthritis.

Multiple independent studies have found that occupational exposure to mineral dust is strongly associated with rheumatologic disease risk.[2–4] Rheumatoid arthritis (RA) has been the condition most strongly implicated in mineral dust inhalation.[5–7] The role that coal and silica dust inhalation may play in the colocation of U.S. regions in which coal mining is concentrated and where there is a high prevalence of arthritis in males is not clear. The impetus for this study was to examine whether coal mining is the nexus between the prevalence of arthritis, especially rheumatoid disease, and being a male in Appalachia.

To address the question of whether a job in coal mining explains, at least in part, the elevated prevalence of arthritis in West Virginia and surrounding areas, we conducted a population-based survey of men aged 50 or over, living in coal mining areas in the Appalachian region. The survey included items to identify occupational exposure to coal dust and to silica exposure, self-reported diagnoses of arthritis (including auto-immune disease subtypes), smoking (given its association with RA), and ergonomic factors that characterize the industrial conditions that miners and other silica-exposed workers face (given their likely association with osteoarthritis.)

Materials and Methods

Data Source.

Data for this study derive from a random digit dial (using both landline and cellular phone sampling) population-based telephone survey of men aged 50 and over with a history of labor force participation who reside in coal mining areas. We targeted persons living in Appalachia (selected counties in Kentucky, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia) with historically high mortality rates from coal workers' pneumoconiosis (CWP) based on data from the National Institute for Occupational Safety and Health (NIOSH).[8] The study was approved by the UCSF Committee on Research; all participants provided verbal consent to proceed with the interview.

Study Sample.

From 30,448 call attempts, we made 7,710 contacts with potential participants, 3,704 were excluded for age, sex, or language (non-English) or because they resided outside the catchment area. There were 3,003 eligible individuals who refused to participate and an

additional 30 who reported no work history, leaving a final study sample of 973 (24% of eligible contacts).

Survey Instrument.

The brief interview (average 10 minutes) addressed employment, smoking history, sociodemographics, and arthritis and related diagnoses. Where appropriate, questions were adapted from standard survey items, most importantly in assessing self-report of a health care provider diagnosis of a health condition, the approach used by the U.S. National Health Interview Survey. Duration and type of coal mining experience was ascertained, as well as type and duration of exposure to inhaled dusts (employment for one year or more that involved “regular exposure to breathing dusty air”). The employment section also included a 13-item list of physical work hazards (e.g. lifting, bending, using power tools), experienced regularly on any job held for at least one year. The health section ascertained whether the respondent had ever received a diagnosis from a health professional of arthritis of any kind, with follow-up items to specify rheumatoid arthritis, psoriatic arthritis, or gout. Other autoimmune conditions, including systemic lupus erythematosus (SLE), psoriatic arthritis (PSA) and systemic sclerosis (SSc), were also queried. All respondents also were asked about joint swelling, stiffness, or pain, and those who responded affirmatively were asked if they had ever received oral glucocorticoids (“prednisone or steroid pills”) in treatment for those symptoms.

Disease Classification.

Arthritis was based on an affirmative response to the primary question about receiving a health care provider’s diagnosis of arthritis. Rheumatoid arthritis was defined based on the follow-up question about type of arthritis, restricted to individuals who also reported receiving glucocorticoids for joint symptoms. A non-RA arthritis category was also defined, including all those who responded positively to the initial arthritis question, but did not meet the study definition of RA. This category is likely to be predominately degenerative arthritis, but includes RA without corticosteroid use as well as persons with other autoimmune arthritis. Our rationale for these definitions was to increase specificity of the RA classification, recognizing that the non-RA category as a result may be less precise.

Exposure Classification.

We categorized coal and silica dust exposure based on questionnaire responses. Coal mining was based on either occupational history of coal mining employment or self-report of coal dust exposure. Other silica dust exposure (among occupations other than coal mining) was based on affirmative responses to any of a list of seven categories of exposure: silica, sand, or concrete dust; sandblasting; rock drilling or roof bolting; rock crushing or quarry work; foundry work; concrete finishing, cutting, or drilling; or masonry work or tip-pointing (items did not specifically elicit employment in selected other, less frequent silica trades in the region such as glass making or pottery works). We assessed lifetime employment without regard to longest held job, but did elicit total years of employment in dusty jobs. On an empiric basis, the ergonomics score based on the check list that we developed for this study was dichotomized at the top quartile (11–13 points vs. <11 points).

Statistical Analysis.

We used multivariable logistic regression analysis to model separately the risk of all arthritis, RA, and non-RA arthritis associated with coal mining employment and other silica exposure, and in additional models, either exposure. All models controlled for age, race/ethnicity (Hispanic or non-white vs white non-Hispanic) smoking status (current, former, never), and for high level of ergonomics exposure. We also calculated the population attributable fraction (PAF) of prevalence to estimate the proportion of prevalent cases (in males) that could be attributed to coal and/or silica exposure, following the method originally proposed by Greenland and Drescher that uses maximum likelihood estimates from multivariable logistic regression models. [9] We tested interaction terms between coal/silica exposure and smoking status for the odds of disease. To examine further potential interaction between ergonomic factors and coal/silica, we carried out an analysis stratified by level of ergonomic factors and conducted a formal test of interaction between high ergonomic score and coal/silica exposure. Statistical analyses were carried out in SAS v9.4 and Stata v15.

Results

Of the 973 respondents meeting study entry criteria, 888 (91%) were white; the mean age was 66 years (Table 1). There were 852 (87%) who were ever smokers, among whom the mean pack-years was 29.8 (median, 22). Over half of the respondents reported having received a health care provider's diagnosis of arthritis. A diagnosis of RA was reported by 188 (19%), but restricting this to a more conservative case definition of RA with glucocorticoid treatment at any point yielded a disease prevalence of 12%. Three percent of those surveyed (n=30) reported at least one non-RA autoimmune condition. The prevalence of these autoimmune conditions, was as follows: SLE, 7; SSc, 5; and PSA, 20. There was overlap among diagnoses including 11 who also were in the RA with glucocorticoids group.

More than one in four respondents (n=266; 27%) reported employment in coal mining, 50% of whom reported work underground, which confers a higher exposure to coal dust (Table 2). The mean duration of coal work employment was 21±13 years (60 miners had worked 30 years or more). Independent of coal mining experience, over half (54%) of those with any current or past employment reported regular exposure to dusty air, with a mean duration of 22±14 years (data on length of exposure not in Table). Of all 973 surveyed, 400 (41%) responded positively to at least one of the seven-item silica exposure checklist. Among the 133 underground coal miners, 78 (59%) reported rock drilling or roof bolting work, a coal mining task recognized to confer high silica exposure.[10] A total of 455 respondents (47%) reported either coal mining or silica dust exposure.

Table 3 shows the frequencies of 13 work-related ergonomic factors experienced on any job for one year or longer "on a daily or almost daily basis." The exposure prevalence differed significantly in three-way comparisons among coal mining, other silica exposed, and all others, with a substantially lower prevalence in the latter group. Those reporting 11 or more factors comprised 30% of the entire group, but characterized more than half of the coal and other silica exposed while only 12% of all others.

Table 4 presents the estimated odds for all arthritis, RA, and arthritis without RA. We estimated the odds for RA excluding the 407 respondents reporting non-RA arthritis or other rheumatic autoimmune diseases (SLE, systemic sclerosis, or psoriatic arthritis) without concomitant RA; models for non-RA arthritis excluded those reporting RA (n=112). Coal mining was associated with more than double the odds of all arthritis (OR 2.3; 95% CI, 1.6, 3.2). The estimated odds ratio of RA associated with coal mining was 3.6 (95% CI 2.1, 6.2) and for non-RA arthritis it was 2.0 (95% CI 1.4, 2.9). Silica exposure, exclusive of coal mining, was also associated with increased odds of any arthritis (OR 1.8; 95% CI 1.2, 2.6), RA (OR 2.1; 95% CI 1.1– 3.9) and non-RA arthritis (OR 1.7; 95% CI 1.2, 2.6). Exposure to 11 to 13 ergonomic factors was associated with a statistically significant and increased odds of any arthritis (OR 1.5; 95% CI 1.1–2.0) and non-RA arthritis (OR 1.4; 95% CI 1.01–2.0), while the odds of RA was slightly higher, but the confidence interval did not exclude 1.0 (OR 1.6; 95% CI 0.97–2.8). Current smoking was associated with double the odds of RA (OR 2.0; 95%; 1.1–3.9) but was not associated with either any arthritis or non-RA arthritis. Former smoking had no statistically significant associations with disease status. There was no statistical evidence supporting an interaction effect for smoking and coal or silica exposure in association with disease in any of the models.

To examine the potential interaction between ergonomic factors and coal/silica exposure for the odds of arthritis, we carried out an analysis stratified by level of ergonomic factors. Among those reporting 11–13 ergonomic factors (n=296), combined coal or silica was not statistically significantly associated with the odds of all arthritis (OR 1.5; 95% CI 0.8–2.7). Among the stratum with a lower ergonomic burden (n=677), the odds ratio was higher and statistically significant (OR 2.2; 95% CI 1.6, 3.1). A formal test of the interaction term between coal or silica exposure and ergonomic factors, however, was not statistically significant (p=0.24).To assess the coal work and silica exposure burden for all arthritis and RA, we estimated the PAF for either coal or silica exposure and for coal and silica separately (Table 5). For coal or silica, the PAF for all arthritis was 29% (95% CI 21 to 37%); for RA, the PAF was 44% (95% CI 31 to 54%). The major contributor was coal mining: for all arthritis and for RA, the PAF was 20% and 33%, respectively.

Discussion

In this population-based study of arthritis in Appalachia, one in two males over 50 reported arthritis; more than one in ten met our case definition of RA. Just over a quarter reported coal mining work and 47% altogether either had been coal miners or had been otherwise occupationally exposed to silica. Because this exposure was common and, because the odds of RA were substantially increased in association with such exposure, we estimated that fully a third of the RA cases in the men in the study were attributable to coal work and, combining that with other silica exposures, the PAF was 42%.

Our findings are consistent with prior studies of coal and silica exposure. In the early 1950s, there were nearly simultaneous observations that both silica dust (nearly pure silica “flour”) and coal mining work were associated with RA. These observations were made by Colinet in Belgium and Caplan in the UK.[11–13] By the 1990s, researchers identified mineral dust as a factor in a range of autoimmune diseases.[2–4, 14,15] Although much of the biomedical

literature has focused on silica, there is emerging recognition that coal dust (with likely silica co-exposure, much of it of a particle size in the respirable range) represents an important factor in what has come to be recognized more broadly as “coal mine dust lung disease.”[16,17]

Despite this, there has been relatively little study of RA among U.S. coal miners. Nearly 50 years ago, a 1969 community based study that included 560 miners aged 20 to 69 in West Virginia observed that radiographic osteoarthritis of the hands was present in 40.2% of the miners.[18] A 1973 serologic study of 207 Pennsylvania and West Virginia underground coal miners, all with radiographic disease, found 6% positive for rheumatoid factor (RF) and 34% positive for antinuclear antibodies (ANA).[19] Contemporaneous clinical studies of coal miners from the same region suggested that exposure-related RA was more common than appreciated.[20,21] Only one other study of rheumatologic disease in Appalachian coal miners has appeared since that time (1981), finding that, among 353 (130 without radiographic lung disease), 69 (19.5%) were RA positive.[22] A recent extensive review of occupational RA included only brief mention of coal mining and no recent citations on that subject.[23]

The differences that we observed in coal mining associated odds of RA juxtaposed with odds for all other arthritis suggest interesting insights. The estimated coal mining odds for RA (OR 3.5) were greater than for all other arthritis (OR 2.0), consistent with a strong relationship to autoimmune arthritis in particular. The odds for RA associated with other silica, however, was only slightly higher than that for other arthritis, although most of those with silica exposure had concomitant coal mining experience.

We recognized, a priori, that ergonomic exposures in coal mining might also be associated with increased arthritis risks. This was, in fact, the case (OR 1.5 for all arthritis, 1.7 for RA, and 1.4 for arthritis excluding RA). Ergonomic factors with established relationships to degenerative arthritis include: kneeling, bending, squatting, crawling, whole body vibration, lifting heavy loads, and repetitive motion.[24–29] In degenerative arthritis of the knee, coal mining-specific data show a strong link to disease.[30–36] It is reasonable to assume that this can be generalized to other body parts as well. Thus, the arthritis that we observed is consistent with the pattern of ergonomic factors reported by the coal (and silica) exposed participants in our study. Nonetheless, ergonomics alone does not account for all the associated odds, given that our multivariable modeling of the coal mining odds ratio for arthritis and RA took into account ergonomic factors. Indeed, the association of a high ergonomic load with RA was of a similar magnitude as that for arthritis overall. Further, we did not identify a significant interaction between ergonomic exposures and coal or silica for arthritis risk, although study power was limited, with fewer than 300 in the stratum with a heavy ergonomic load. We also cannot exclude unmeasured confounding that might explain the associations we observed, for example, body habitus or socio-economic factors beyond work itself.

Our findings have potential limitations. The diagnosis of RA we used was based on respondent report of a health care provider’s diagnosis. This is the approach used in many questionnaire-based studies, most notably the U.S. National Health Interview Survey. Nonetheless, self-reported disease can be subject to random misclassification or reporting

bias. Random misclassification of disease should have resulted in a reduced association of RA with coal or silica exposures. In contrast, systematic reporting bias could lead persons with coal mining histories to be more likely to report disease, thus leading to a false association. Our telephone survey length was constrained such that we could not ascertain duration or dosing of reported corticosteroids nor obtain a detailed history of other disease modifying antirheumatic drugs (DMARDs). Further, we did not have access to medical records, serologic data (e.g., for rheumatoid factor), or physical examinations, sources of confirmatory data that mitigate against reporting bias. Our finding of a 53% prevalence of arthritis overall, although high, is consistent with estimated rates in Appalachia.[1] Nonetheless, it is probable that some persons with degenerative arthritis but not autoimmune disease misreported their condition as RA. In particular, the term “rheumatism” as commonly used may manifest geographic regional differences that magnify this problem in the counties from which we recruited.[37] We attempted to address this, in part, by using a conservative definition of disease that also included reported glucocorticoid use. In addition, the higher coal mining associated OR that we observed for RA as compared to other arthritis, noted previously, argues against selective over-reporting of arthritis as RA amongst coal miners. Further, the association with current smoking for RA (2.0), but not all arthritis (1.2), is consistent with previous observations specific to RA generally but also in silica exposure.[6] Our observed overall response rate (24%), although similar to that reported for non-Federal telephone surveys, is less than that of the Behavioral Risk Factor Surveillance System.[38] Because we do not have information on non-participants we cannot assess unmeasured selection effects this may represent. Finally, the high prevalence of disease in the population we studied could lead to overestimation of the association with coal and silica when relying on prevalence odds ratios.

In summary, our findings of increased odds ratios for arthritis and RA among coal miners in Appalachia are robust, unlikely explained by biased reporting or confounding, and are consistent with other studies, primarily of silica exposure outside of coal mining. This association, at the regional level of Appalachia, is relevant to the delivery of health care services and to individual case attribution and compensation. Tertiary prevention of disease progression and disability is especially noteworthy. Given that treatment guidelines for RA indicate that a disease-modifying agent should be initiated soon after onset of disease, earlier disease detection could be achieved through targeted surveillance among current and former coal miners. However, the results reported here suggest that primary prevention of arthritis due to workplace protections for dust inhalation may reduce the prevalence of arthritis in general and RA in particular in the first place.

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Significance and Innovations

- Silica has a well-established association with rheumatoid arthritis, but coal mining, especially in the U.S., has not been well-studied.
- This is the first modern U.S. population-based study of degenerative and rheumatoid arthritis showing a strong association with coal mining.
- The potential occupational contribution to arthritis in a current or retired coal miner should be considered by clinicians treating such patients.

Table 1.

Subject Demographics, Smoking Status, and Arthritis Diagnoses

Characteristics	Frequency
Age in years, mean±SD	66.0±9.6
Race and ethnicity, No. (%)	
White, Non-Hispanic	88 (91%)
Black	31 (3%)
Hispanic	16 (2%)
Asian/Other	38 (4%)
Smoking status	
Never smoked, No. (%)	452 (46%)
Former smoker, No. (%)	400 (41%)
Current smoker, No. (%)	121 (12%)
Pack years (among ever smokers), mean±SD median (25^{th}-75^{th} percentile)	29.8±28.8 22 (9 – 43)
Reported health care provider arthritis diagnosis, No. (%)	
Any arthritis diagnosis reported	517 (53%)
Arthritis, excluding rheumatoid arthritis (RA)	329 (34%)
Any RA reported	188 (19%)
RA, without ever prednisone use	76 (8%)
RA, with ever prednisone use	112 (12%)
Any other autoimmune arthritis (non-mutually exclusive)	30 (3%)
Systemic lupus erythematosus (SLE)	7 (1%)
Systemic Sclerosis (SSc)	5 (1%)
Psoriatic arthritis	20 (2%)

Table 2.

Exposure Status for 973 Survey Respondents with Any Work History

Employment Status and Exposures	n (%)
Ever employed	973 (100%)
Currently employed	407 (42%)
Any coal mining employment	266 (27%)
Underground coal mining	133 (14%)
Any dust exposure	524 (54%)
Non-silica dust exposure	124 (13%)
Silica exposure, any	400 (41%)
Silica exposure, non-coal *	189 (19%)
Coal mining and/or silica exposure)	455 (47%)

* Coal and silica are not wholly overlapping: 55 respondents with coal employment did not also report any of a checklist of seven sources silica exposure: silica, sand, or concrete dust; sandblasting; rock drilling or roof bolting; rock crushing or quarry work; foundry work; concrete finishing, cutting, or drilling; masonry work or tip-pointing.

Table 3.

Ergonomic Factors Associated with Coal and Other Silica Exposure

Ergonomic Factor	All Respondents % (n=973)	Coal Mining % (n=266)	Other Silica % (n=189)	Neither % (n=518)
Lifting/carrying >30 lbs	69.8	83.1	93.7	54.2
Arms overhead	55.3	64.3	77.8	42.5
Knee bend/squat/kneel	69.3	82.7	91.0	54.4
Back bend/twist	68.1	81.6	88.4	53.9
Hand grip/wrist bend	71.8	85.0	89.9	58.5
Shaking/vibrating equipment	36.3	57.1	58.7	17.4
Hammer/chisel/saw/drill	50.5	71.1	80.4	29.0
Stoop over	71.1	82.7	91.0	57.9
Pneumatic tools	32.7	51.5	56.1	14.5
Pedal/treadle	37.3	53.0	46.0	26.1
Push/pull >50 lbs	55.5	71.1	80.4	38.4
Neck twist/bend	51.7	73.3	66.7	35.1
Stand > 8 hrs./day	65.6	73.3	83.6	55.0
High exposure (>10 factors)	30.4	50.8	53.4	11.6

*All measures differed at $p<0.001$ across the 3 occupational groups.

Table 4.

Multivariate Analysis: Arthritis and Rheumatoid Arthritis associated with Coal and Silica Exposure Adjusted for Smoking, Ergonomic Factors, Age, and Race/Ethnicity

	All arthritis Model n=973	**Rheumatoid Arthritis Model n=566***	**Non-RA Arthritis Model n=861****
Associated Factors	OR (95% CI)	OR (95% CI)	OR (95% CI)
Coal and Silica exposure			
Coal mining work	2.3 (1.6, 3.2)	3.6 (2.1, 6.2)	2.0 (1.4, 2.9)
Silica, no coal exposure	1.8 (1.2, 2.6)	2.1 (1.1, 3.9)	1.7 (1.2, 2.5)
Smoking			
Current	1.2 (0.8, 1.9)	2.0 (1.1, 3.9)	1.1 (0.7, 1.7)
Former	1.1 (0.8, 1.5)	1.2 (0.7, 1.9)	1.1 (0.8, 1.5)
Ergonomic exposure			
11–13 factors	1.5 (1.1, 2.0)	1.6 (0.97, 2.8)	1.4 (1.01, 2.0)
Age (per year)	1.03 (1.01, 1.04)	1.04 (1.01, 1.06)	1.03 (1.01, 1.04)
Race/ethnicity			
Hispanic ethnicity or Non-white race	1.4 (0.8, 2.4)	1.3 (0.6, 3.0)	1.5 (0.9, 2.5)

For coal and silica, referent category=neither exposure; for smoking, referent=never smoker; for ergonomic exposure, referent category= 0 to 10 factors; for race/ethnicity, referent category = White, non-Hispanic.

*Excludes 407 reporting non-RA arthritis or selected autoimmune diseases without concomitant RA.

**Excludes 112 participants reporting RA and glucocorticoid treatment.

Table 5.

All Arthritis and RA Population Attributable Fraction Associated with Coal and Silica Exposure

Exposure	**All Arthritis**	**RA**
	PAF (95% CI)	PAF (95% CI)
Coal and Silica exposure		
Either exposure	29% (21 to 37%)	44% (31 to 54%)
Coal mining work	20% (14 to 25%)	33% (26 to 40%)
Other occupational silica exposure	10% (5 to 14%)	10% (4 to 16%)

RA = Rheumatoid Arthritis; PAF = Population Attributable Risk

For coal or silica exposure, for all arthritis OR = 2.1 (95% CI 1.5 to 2.8); for RA, OR =2.9 (95% CI 1.8 to 4.9), For coal mining work and other silica in model adjusting for each, see ORs in Table 4. All estimates derived from multivariable models adjusted for age, race/ethnicity, smoking, and ergonomic exposures.