Original research

# Dusty trades and associated rheumatoid arthritis in a population-based study in the coal mining counties of Appalachia

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## ABSTRACT

**Objectives** We previously showed increased coal mining-associated risk of rheumatoid arthritis (RA). Using additional survey data, we sought to delineate this risk further.

**Methods** We used data from two cross-sectional, random-digit-dial, population-based surveys (males;≥50 years) in selected counties in the Appalachian region of the inland, mid-Atlantic USA with elevated pneumoconiosis mortality. Surveys ascertained age, smoking, coal mining and non-coal silica exposure jobs. In a subset, we surveyed ergonomic exposures, scored by intensity. We queried diagnosis of RA, corticosteroid use, and, in a subset, use of disease modifying antirheumatic drugs (DMARDs). Multivariable logistic regression modelled RA risk (defined by glucocorticoid or DMARDs use) associated with coal mining employment, other silica exposure, smoking status, and age and ergonomic exposures.

**Results** We analysed data for 2981 survey respondents (mean age 66.6 years; 15% current, 44% ex-smokers). The prevalence of glucocorticoid-treated and DMARD-treated RA was 11% and 4%, respectively. Glucocorticoid-treated RA was associated with coal mining (OR 3.5; 95% CI 2.5 to 4.9) and non-coal mining silica exposure (OR 3.2; 95% CI 2.4 to 4.4). For DMARD-treated RA, the odds associated with coal mining and other silica remained elevated: OR 2.3 (95% CI 1.18, 4.5) and OR 2.7 (95% CI 1.51, 5.0), respectively. In the same model, the highest intensity ergonomic exposure also was associated with increased odds of RA (OR 4.3; 95% CI 1.96 to 9.6).

**Conclusions** We observed a strong association between coal mining and other silica-exposing dusty trades and RA. Clinicians and insurers should consider occupational histories in the aetiology of RA.

## Key messages

**What is already known about this subject?**

- Occupational silica exposure is a recognised, although underappreciated, risk factor for rheumatoid arthritis (RA). Coal mining risk of RA, especially in the modern era, has been given less attention.
- A recent study showed an increased odds of RA associated with coal mining in Appalachia (a region of the eastern USA, inland from the mid-Atlantic).

**What are the new findings?**

- The odds of RA increase with higher intensity and longer duration of likely silica exposure in coal mining.
- There was an interaction between coal mining exposure and smoking: the risk of RA associated with coal mining was greater among former smokers, and those with less cumulative exposure to cigarettes.
- The survey results also identify a concomitant ergonomic exposure risk for RA.

**How might this impact on policy or clinical practice in the foreseeable future?**

- Clinicians should consider occupational histories in the aetiology of RA in both current and retired workers. Those considering policy from a social insurance perspective should recognise the strong link between RA and coal mining or other silica exposure jobs.

## INTRODUCTION

Occupational exposures have a well-established association with rheumatoid arthritis (RA).[1] Work-related exposure to silica, in particular, has been linked to RA, as well as to other autoimmune diseases.[2 3] Traditional silica sources have included silica in abrasives, including abrasive blasting, quarrying and stone cutting, and foundry work and, more recently, heavy silica exposure in artificial stone fabricating has been identified to carry risk of disease.[4]

Coal mining also is an RA-associated occupation, presumed at least in part due to concomitant silica exposure.[5] The increased risk of RA among coal miners was originally established in Great Britain in the post-World War Two period.[6] In contrast, other than a few early reports, US coal mining generally has not been presumed to carry notable RA risk.[7–9] To address this knowledge gap, we previously surveyed selected counties in Appalachia with increased mortality due to coal worker's pneumoconiosis (CWP).[10] Appalachia is a mostly rural area of the inland, mid-Atlantic US that has had large geographically concentrated coal mining operations. That population-based study, carried out among 1000 persons with and without coal mining work histories, found that underground coal mining did indeed substantially increase the odds of RA.[11]



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We wished to build on those findings by performing a second, larger study using the same basic survey methods but allowing for a more detailed delineation of occupational exposures. We also collected more detailed information on RA treatment in order to provide additional criteria to define the presence or absence of disease. Our goal was to allow for a pooled analysis of variables identically defined in both surveys, thus tripling the study size so that selected stratified analyses would be feasible, while also allowing for additional analysis limited to the newer survey only, particular in relation to more restrictively defined RA.

## METHODS

Data for this study derive from two cross-sectional, random-digit dial (RDD) population-based telephone surveys. The RDD surveys included landline and cellular phone sampling targeting exchanges likely to be in counties in Appalachia (including parts of Kentucky, Ohio, Pennsylvania, Tennessee, Virginia and West Virginia) with historically high mortality rates from CWP. We identified the targeted areas using data from the National Institute for Occupational Safety and Health.[10] We limited eligibility for survey participation to males 50 and over who were English language speakers, had a history of any past or current labour force participation, and confirmed current residence in one of the targeted counties.

This analysis includes data collected in two separate RDD surveys with identical sampling methods. The initial sample, described previously, included 973 men surveyed in 2017.[11] In the second sample, conducted in 2019, there were 62 948 call attempts resulting in 23 729 (38%) contacts with potential participants; 15 731 (66% of contacts) were ineligible because of age, sex, language, lack of labour force participation, or county of residence. Among eligible individuals, 5990 declined participation, yielding 2008 respondents with data available for analysis (25% of eligible contacts). For analyses combining both samples, the study population consisted of 2981 survey respondents (online supplemental figure 1).

Study interviews averaged 10 min in the 2017 survey and 18 min in the more extensive 2019 survey. Both surveys contained identically worded core items addressing employment, smoking history, sociodemographics and arthritis and related diagnoses. They both ascertained duration and type of coal mining experience, as well as exposure to inhaled dusts in non-coal mining jobs. The health sections queried whether the respondent had ever received a diagnosis from a health professional of arthritis of any kind, with follow-up items specifying RA, psoriatic arthritis or gout. The two surveys also elicited diagnoses of other autoimmune conditions, including systemic lupus erythematosus, psoriatic arthritis and systemic sclerosis. Interviewers asked about joint swelling, stiffness or pain, and asked those who responded affirmatively if they had ever received oral glucocorticoids ('prednisone or steroid pills') in treatment for those symptoms.

The 2019 survey included expanded batteries with items that were not present in the 2017 pilot detailing additional coal mining activities in order to further delineate exposure (see Coal and Silica Exposure) and additional questions related to treatments received for arthritis, in order to improve the specificity of the self-reported diagnoses of RA (see Disease Classification, below). The 2019 survey also restructured its assessment of ergonomic factors in order to better differentiate among higher intensity exposures (see Ergonomic Exposures Classification, below).

Arthritis was defined by an affirmative response to a primary stem question about receiving a healthcare provider's diagnosis of arthritis. We defined RA based on a follow-up item about type of arthritis, further defined by also reporting having received glucocorticoids for joint symptoms. An alternative, more specific definition for RA, limited to items elicited in the 2019 survey only, required a diagnosis of RA and report of receiving at least one of a standard list of disease-modifying antirheumatic drugs (DMARDs): methotrexate, sulfasalazine, hydroxychloroquine, azathioprine, leflunomide, etanercept, adalimumab, infliximab, golimumab, certolizumab, tocilizumab, abatacept, rituximab or tofacitinib. As a sensitivity analysis, we also created a restrictive definition requiring both glucocorticoids and a DMARD. We defined a category of non-RA arthritis for all those who responded positively to the initial arthritis question, but did not meet the main study definition of RA. This category is likely to be predominantly degenerative arthritis (osteoarthritis), but includes reported RA without glucocorticoid use (or, in 2019 survey, without DMARDs) as well as infrequent reports of other autoimmune arthritis.

We defined coal mining based on survey-reported occupational history of any coal mining employment, with additional survey items eliciting underground and/or surface coal mining. Other silica dust exposure (not from coal mining) was defined by affirmative responses to any of a list of specific job tasks including: underground mining (other than coal); work with silica, sand or concrete dust; sandblasting; rock drilling or roof bolting (in other mining); rock crushing or quarry work; foundry work; concrete finishing, cutting or drilling; or masonry work or tip-pointing. The surveys did not specifically elicit employment in other silica trades that are less common in this region, such as glass-making or ceramic manufacturing. The expanded 2019 survey elicited more detailed information about coal mining exposure, allowing for identification of coal jobs that likely would result in higher intensity silica exposure: roof bolter, slope or shaft construction work, and, in surface mining, bulldozer, dragline or scraper operator. The 2019 survey ascertained the number of years spent working underground and the proportion of that time spent at the coal face, as that also confers higher silica exposure.

The 2019 survey elicited responses on multiple ergonomic exposures from any occupation grouped by the body part involved or physical movement (eg, hand/wrist twisting). The categories surveyed included: neck and upper extremities (three items); hands (two items); back (four items); feet and lower extremities (three items); and work activities involving vibration (three items). Respondents reporting any work-related ergonomic exposures in these five categories were asked to specify the number of years worked in such jobs. We used these responses to generate a summary score in which one point was given for any group in which the respondent endorsed all of its items and reported at least 5 years exposure. This method yielded a summary score ranging from 0 to 5. Although ergonomic exposures were elicited in the 2017 survey, the battery was more limited, had a lower threshold of positive response, and did not allow application of the same scoring schema; thus those data are not included in this analysis.

In both surveys, smoking exposure was assessed in the same manner, including age started, number of years smoked (for former smokers), and average number of cigarettes per day. This allowed for categorisations based on smoking status—never/former/current—and on number of years of exposure, yielding an estimate of pack-years of exposure. Respondents who had quit smoking fewer than 3 years prior to interview were considered recent smokers and included in the same category as current

**Table 1** Characteristics of 2981 survey participants from two population-based samples

| Characteristics | 2017 Sample (n=973) | 2019 Sample (n=2008) | Combined Samples (n=2981) |
|---|---|---|---|
| Sociodemographics | n(%) (unless otherwise noted) | | |
| Age, mean±SD | 66.0±9.6 | 66.9±9.7 | 66.6±9.7 |
| Race/ethnicity | | | |
| Black | 31 (3%) | 48 (2%) | 79 (3%) |
| Hispanic | 16 (2%) | 24 (1%) | 40 (1%) |
| Asian/other | 38 (4%) | 61 (3%) | 99 (3%) |
| White, non-Hispanic | 888 (91%) | 1875 (93%) | 2763 (93%) |
| Currently employed | 407 (42%) | 716 (36%) | 1123 (38%) |
| Cigarette Smoking | | | |
| Never smoked | 452 (46%) | 845 (42%) | 1297 (44%) |
| Former smoker | 394 (40%) | 832 (41%) | 1226 (41%) |
| Current/recent smoker | 127 (13%) | 331 (16%) | 458 (15%) |
| Among ever smokers | | | |
| Years smoked, median (IQR) | 25 (12–40) | 25 (13–40) | 25 (12–40) |
| Pack-years, mean±SD | 29.8±28.8 | 32.0±30.3 | 31.3±29.8 |
| Arthritis | | | |
| No dx of arthritis reported | 456 (47%) | 837 (42%) | 1293 (43%) |
| Any arthritis dx reported | 517 (53%) | 1171 (58%) | 1688 (56%) |
| Arthritis, excluding RA | 329 (34%) | 759 (38%) | 1088 (37%) |
| Any RA reported | 188 (19%) | 412 (21%) | 600 (20%) |
| RA, with glucocorticoids | 112 (12%) | 202 (10%) | 314 (11%) |
| RA, with DMARD | – | 88 (4%) | – |
| RA, with DMARD and glucocorticoids | – | 62 (3%) | – |
| Exposures | | | |
| Any coal mining exposure | 181 (19%) | 409 (20%) | 590 (20%) |
| Years coal mining, median (IQR) | 19 (7–30) | 17 (5–30) | 18 (5–30) |
| Underground mining | 133 (14%) | 263 (13%) | 396 (13%) |
| Surface mining | 97 (10%) | 210 (10%) | 307 (10%) |
| High intensity silica coal mining jobs | – | 258 (13%) | – |
| Silica exposure, not from coal mining | 264 (27%) | 557 (28%) | 821 (28%) |
| Ergonomic exposure score, median (IQR) | – | 2 (0–3) | – |
| Ergonomic score=0 | – | 613 (31%) | – |
| Ergonomic score=1 | – | 326 (16%) | – |
| Ergonomic score=2–3 | – | 613 (31%) | – |
| Ergonomic score=4–5 | | 456 (23%) | |

All participants male, ≥50 years old. Missing data for years smoking: 14 (2017), 23 (2019); see the Methods section for drugs included.
DMARD, disease-modifying antirheumatic drug; RA, rheumatoid arthritis.

smokers. Those who did not report intensity or duration of exposure were excluded from pack-year analyses.

We compared the demographic, occupational and arthritis prevalence characteristics of the 2017 and 2019 samples. As shown in table 1, the frequencies of all characteristics were extremely similar, supporting a pooled analysis of the two samples for these measures. Using multivariable logistic regression analyses, we modelled the risk of all arthritis, RA (defined by glucocorticoid use), and non-RA arthritis associated with coal mining employment and other silica exposure, or either exposure. These models controlled for age and smoking status (current, former, never). We also tested interaction terms between coal/silica exposure and smoking status for the odds of disease.

Using the maximum likelihood estimates from the regression models, we calculated the population attributable fraction (PAF) of RA prevalence to estimate the proportion of prevalent cases among men that could be attributed to coal and/or silica exposure.[12] We further estimated the odds of RA from models stratified by never versus ever smoking and, among ever smokers, stratified by former vs current or recent and by years of exposure (dichotomised at the median, 25 years), also testing interaction terms in these analyses. As a sensitivity analysis, we re-estimated the main models using generalised estimating equations (GEE) including the survey group (2017, 2019) as an additional variable.

Using the additional data only available in the 2019 survey, we modelled the risk of disease using the overall approach described above but adding the two specific definitions of RA with DMARDs and with both glucocorticoids and DMARDs. In these models, we additionally included an ordinal measure of ergonomic exposure from the 2019 survey based on score (0, 1, 2–3 or 4–5 points). We further defined coal mining exposure based on high intensity silica exposure tasks (available in the 2019 survey only) and on the number of years in underground mining. Each of these models also controlled for age and smoking (never/former/current).

To reduce the chance of misclassification bias, all models of RA (any definition) or non-RA arthritis excluded subjects who reported arthritis but did not meet the criteria for the diagnosis under consideration. For example, models of RA with glucocorticoids (main study definition of RA) excluded subjects who reported arthritis but not RA or who reported RA but not glucocorticoids. Thus, the reference population in each model is comprised only of individuals without any arthritis. Statistical analyses were carried out in SAS V.9.4 and Stata V.15.

## RESULTS

The two study samples (table 1) were very similar in all measured variables (as noted in the Methods section). Respondents were aged 66.6 years on average and were predominantly white non-Hispanic. Fewer than half were employed at the time of the survey (by study eligibility, all had prior employment). Cigarette smoking exposure was common in both samples, with 15% reporting current smoking and 44% reporting previous smoking. Among those with any smoking history, the median duration of exposure was 25 years and the mean cumulative exposure was 31.3 pack-years.

Over 50% of respondents reported a healthcare provider's diagnosis of arthritis, and 20% reported RA. Restricting the definition of RA to those who also reported receiving glucocorticoids for joint symptoms reduced the prevalence of RA to 11%. In the 2019 sample, 88 respondents (4% (95% CI 3% to 5%) of 2008) reported a diagnosis of RA along with at least one DMARD prescription; and 62 (3% (95% CI 2% to 4%)) reported both DMARDs and glucocorticoids.

Coal mining was common in this population. Twenty percent reported any experience in coal mining and, among that group, the median duration of exposure was 18 years; about two-thirds (396 of 590) reported underground coal mining work. In the 2019 sample, 13% reported coal mining tasks with a likelihood of high intensity silica exposure. Ergonomic exposure factors were also common among the 2019 respondents, with over half the sample reporting at least

**Table 2** Arthritis conditions associated with coal and silica exposure, adjusted for smoking and age combined datasets (2017 and 2019 surveys)

| | Arthritis (Any Type) | Non-RA arthritis (Excluding RA) | RA* (Excluding non-RA) |
|---|---|---|---|
| | (n=2981) | (n=2667) | (n=1607) |
| Arthritis prevalence | 57% (55%–58%) | 46% (44%–48%) | 11% (9%–12%) |
| Risk factors | Odds Ratios (95% confidence intervals) | | |
| Coal and silica exposure | | | |
| Coal (±silica exposure) | 2.3 (1.8 to 2.8) | 2.1 (1.7 to 2.5) | 3.5 (2.5 to 4.9) |
| Silica exposure only | 2.0 (1.7 to 2.4) | 1.8 (1.5 to 2.2) | 3.2 (2.4 to 4.4) |
| Neither | Referent | Referent | Referent |
| Age | 1.02 (1.01 to 1.03) | 1.02 (1.01 to 1.03) | 1.02 (1.01 to 1.03) |
| Smoking | | | |
| Current/recent smoker | 1.1 (0.9 to 1.4) | 1.0 (0.8 to 1.3) | 1.7 (1.2 to 2.5) |
| Former smoker | 1.3 (1.1 to 1.5) | 1.3 (1.1 to 1.5) | 1.5 (1.2 to 2.1) |
| Never smoked | Referent | Referent | Referent |

OR for age expressed per year of age. Recent smokers include those who stopped in past 3 years.
*RA definition based on report of doctor's diagnosis of RA, plus treatment with glucocorticoids.
RA, rheumatoid arthritis.

5 years of work in jobs that involved two or more categories of ergonomic exposures.

The primary outcome of RA, defined by glucocorticoid use along with a reported diagnosis of RA, was associated with both coal mining (OR 3.5; 95% CI 2.5 to 4.9) and non-mining silica exposure (OR 3.2; 95% CI 2.4 to 4.4; table 2). This model also showed the anticipated increased odds of RA associated with both current and former smoking. Arthritis as a whole was also significantly associated with the silica exposures and smoking, although to a somewhat reduced degree. Repeating these models using GEE to account for any differences in the two survey samples did not yield substantively different results (online supplemental table 1).

PAF associated with coal mining and non-coal silica exposures for all arthritis, non-RA arthritis and RA, calculated from models that control for age and smoking status are shown in figure 1. The PAF can be interpreted as the proportion of cases of a disease that would be prevented in the absence of the exposures in question. Based on the prevalence of exposure in this population and the increased odds of disease among the exposed, the PAF associated with coal or other silica exposures for RA approaches 50%.

Adding an interaction term for the silica exposure variable with the smoking status variable to the models of all arthritis and non-RA arthritis did not add to the explanatory power of the models. However, there was evidence of interaction (p=0.08) in the RA model. To further explore the relationships

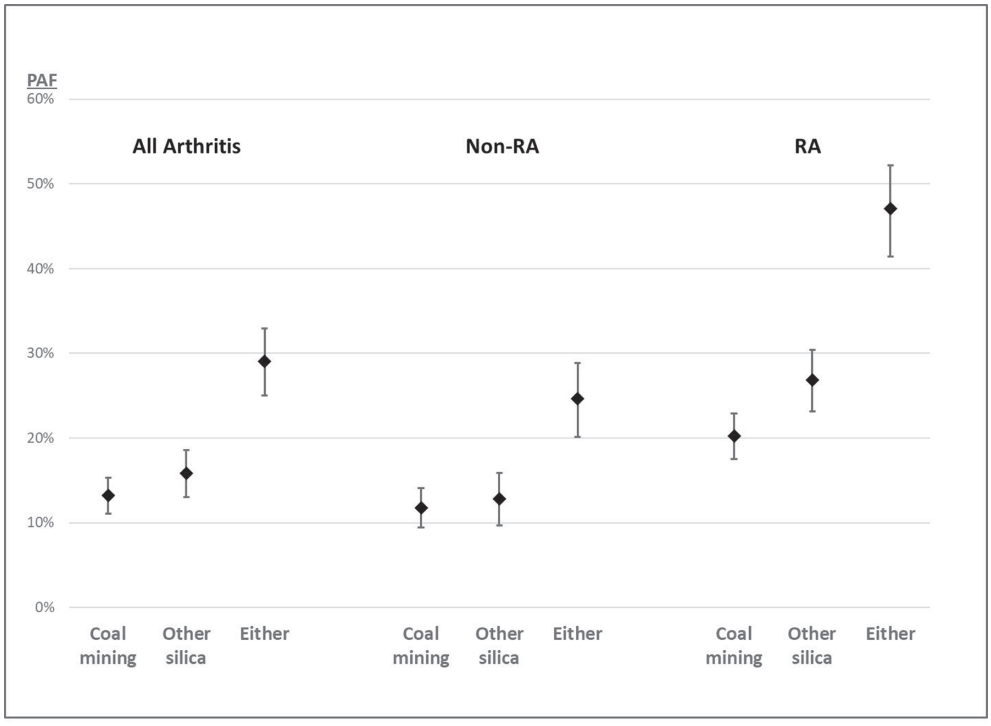


**Figure 1** Population attributable fractions (PAF) for arthritis conditions. Estimates based on logistic regression models using combined 2017 and 2019 surveys, controlling for smoking (never, former, current/recent) and age. Error bars represent 95% CIs. RA, rheumatoid arthritis.

**Table 3** Rheumatoid Arthritis associated with coal mining and other silica exposure, stratified on smoking status

| | | RA Prevalence | Exposure | | |
|---|---|---|---|---|---|
| | | | Coal±other Silica | Non-coal Silica | Interaction term |
| **Stratified models** | **Model n** | **Pe rcent** | **ORs (95% CI) for RA** | | **P value** |
| Never and ever smokers | | | | | 0.84 |
| Never smokers | 729 | 8 | 3.0 (1.7 to 5.2) | 2.9 (1.8 to 4.8) | |
| Ever smokers | 878 | 13 | 3.8 (2.5 to5.8) | 3.5 (2.4 to 5.1) | |
| Former and current smokers* | | | | | 0.02 |
| Former smokers | 615 | 12 | 5.4 (3.3 to 9.0) | 3.5 (2.2 to 5.5) | |
| Current/recent smokers | 263 | 15 | 1.6 (0.8 to 3.6) | 3.2 (1.7 to 6.2) | |
| Shorter and longer smoking* | | | | | 0.02 |
| <25 years | 441 | 11 | 6.5 (3.5 to 12.1) | 4.0 (2.2 to 7.3) | |
| ≥25 years | 419 | 15 | 2.1 (1.2 to 3.7) | 3.1 (1.8 to 5.1) | |

RA definition based on report of provider's diagnosis of RA, plus treatment with glucocorticoids.
Results from logistic regression models controlling for age. All models exclude non-RA arthritis.
Reference group for coal/silica exposure is neither coal nor silica exposure.
Interaction term for coal/silica exposure with smoking status shown.
Recent smokers include those who stopped in past 3 years.
Combined datasets (2017 and 2019 surveys).
*Never smokers and unknown smoking status excluded. Smoking duration missing, n=37.
RA, rheumatoid arthritis.

among smoking and occupational silica exposure in RA, we stratified the sample in several ways (table 3). Dividing the group between ever vs never smokers did not show evidence of any significant difference in odds of RA for coal mining or other silica exposure (p=0.84 for interaction term). Among those with smoking history, however, there were significant interaction effects. In former smokers, the OR for coal mining exposure was 5.4 (95% CI 3.3 to 9.0), compared with 1.6 (95% CI 0.8 to 3.6) among current smokers (interaction term p=0.02). Similarly, the OR for coal mining exposure was 6.5 (95% CI 3.5 to 12.1) among those who had smoked <25 years, compared with 2.1 (95% CI 1.2 to 3.7) among those with 25 or more years of exposure (interaction term p-value=0.02). This effect modification was not apparent for non-mining silica exposure.

Results from analyses limited to 2019 survey data are presented in table 4. Controlling for ergonomic exposures attenuated the associations between arthritis and silica exposures, but most of the ORs for coal or non-coal silica exposures remained elevated and statistically significant. The two alternate, more specific definitions of RA yielded very similar results to the broader definition based on glucocorticoid use alone. In the most restrictive definition of RA, requiring both DMARDs and glucocorticoids (online supplemental table 2), the OR for coal mining increased to 3.0 (95% CI 1.4 to 6.4) and for non-coal silica, 2.9 (95% CI 1.4 to 6.0). The association between ergonomic factors and either definition of RA was quite strong, especially at the highest ergonomic scores. This is in contrast to the more moderate, although still statistically significant, association between the ergonomic factor score and non-RA arthritis.

The second of the three models in table 4 indicates that the high intensity coal mining jobs manifested slightly higher odds of disease compared with lower intensity exposures, but both exposure levels were significantly higher compared with the non-exposed group. The third model shows a gradient of effect based on the number of years spent working underground, from none (ie, surface work only) through 18 or more years. Respondents with the longest exposure had particularly high odds of RA, using the sensitive definition (OR 3.8, 95% CI 1.99 to 7.2).

## DISCUSSION

This analysis of population-based survey data from Appalachia shows that coal mining work and occupational silica exposure are both associated with threefold odds of RA, findings that are similar to our previous analysis among a subset of these data.[11] Moreover, the availability of a combined, larger sample allowed in-depth analysis of the inter-relations among coal mining or other silica exposure, smoking, and RA. This showed that the odds of RA associated with coal mining were greater among former cigarette smokers and those with a lower duration of smoking and that the interaction between smoking and occupational exposure was statistically significant. Further, using data generated only in the newer of the two surveys analysed, a step-up in odds of RA was manifested with greater silica risk coal jobs and longer duration of work underground, supporting a pattern of exposure-response consistent with a causal relationship.

Newer survey data provided greater detail on RA with a history of treatment with DMARDs, a more specific definition of disease. Defining RA in this narrower way reduced the prevalence of disease (from 11% to 4%) but did not substantively affect point estimates of the coal mining-associated odds of disease. This suggests that defining RA based on glucocorticoid treatment even without report of DMARD use provides a reasonable measure of disease and avoids the selection effect of requiring access to prescription medications that can be quite costly and require access to specialty care which is in short supply in this geographical area.

This analysis also benefits from more detailed ergonomic 2019 exposure data than were available in our original 2017 survey. Using this more refined measure, we observed increased odds of both RA and non-RA arthritis, with a heightened exposure response with increasing ergonomic burden. This adds to our previous observation of an ergonomic association using a non-graded measure.[11] It also is consistent with magnitude of risk based on analyses of Scandinavian data in which an association was observed between ergonomic factors and RA risk.[13 14] The potential mechanism of ergonomic risk for osteoarthritis through mechanical stressors is straightforward, although in coal mining this only has been well studied in the case of knee complaints (ie,

**Table 4** Arthritis conditions associated with coal and silica exposure, adjusted for ergonomic exposures, smoking and age (2019 sample only)

| Multivariate logistic models | Any arthritis (Model n=2008) | Non-RA arthritis (Model n=1806) | RA (sensitive) (Model n=1039) | RA (specific) (Model n=925) |
|---|---|---|---|---|
| Prevalence of arthritis by type (95% CI) | 58% (56% to 60%) | 48% (46% to 50%) | 10% (9% to 11%) | 4% (3% to 5%) |
| Model 1: coal and/or silica exposure | ORs (95% CIs) | | | |
| No exposure to coal mining or other occupational silica | Referent | Referent | Referent | Referent |
| Coal mining exposure | 1.8 (1.4 to 2.3) | 1.7 (1.27 to 2.2) | 2.3 (1.52 to 3.6) | 2.3 (1.18 to 4.5) |
| Silica exposure from non-coal occupations only | 1.3 (1.1 to 1.7) | 1.2 (0.97 to 1.6) | 1.8 (1.20 to 2.7) | 2.7 (1.51 to 5.0) |
| Ergonomic hazard score (referent category=0) | | | | |
| one point | 1.5 (1.2 to 2.0) | 1.5 (1.09 to 1.9) | 2.4 (1.30 to 4.2) | 1.8 (0.76 to 4.4) |
| 2–3 points | 2.0 (1.5 to 2.5) | 1.8 (1.43 to 2.4) | 3.2 (1.91 to 5.4) | 2.4 (1.12 to 5.2) |
| 4–5 points | 2.6 (2.0 to 3.5) | 2.3 (1.68 to 3.1) | 5.4 (3.14 to 9.5) | 4.3 (1.96 to 9.6) |
| Model 2: intensity of exposure | | | | |
| No exposure to coal mining or other occupational silica | Referent | Referent | Referent | Referent |
| High silica coal mining exposure | 1.9 (1.4 to 2.6) | 1.8 (1.27 to 2.4) | 2.6 (1.60 to 4.4) | 2.6 (1.21 to 5.5) |
| All other coal mining exposure | 1.6 (1.1 to 2.3) | 1.5 (1.04 to 2.3) | 1.9 (1.05 to 3.6) | 1.9 (0.76 to 4.9) |
| Silica exposure from non-coal occupations only | 1.3 (1.1 to 1.7) | 1.2 (0.97 to 1.6) | 1.8 (1.20 to 2.7) | 2.7 (1.51 to 5.0) |
| Ergonomic hazard score (referent category=0) | | | | |
| 1 point | 1.5 (1.2 to 2.0) | 1.4 (1.09 to 1.9) | 2.4 (1.31 to 4.3) | 1.8 (0.77 to 4.5) |
| 2–3 points | 2.0 (1.5 to 2.5) | 1.8 (1.42 to 2.4) | 3.2 (1.90 to 5.4) | 2.4 (1.11 to 5.2) |
| 4–5 points | 2.6 (2.0 to 3.5) | 2.3 (1.68 to 3.1) | 5.4 (3.12 to 9.4) | 4.3 (1.94 to 9.5) |
| Model 3: underground coal mining exposure | | | | |
| No exposure to coal mining or other occupational silica | Referent | Referent. | Referent | Referent |
| No underground work | 1.5 (1.0 to 2.2) | 1.5 (1.02 to 2.2) | 1.5 (0.78 to 2.9) | 1.5 (0.58 to 4.1) |
| 1–17 years | 1.6 (1.1 to 2.4) | 1.5 (0.96 to 2.2) | 2.4 (1.27 to 4.4) | 2.7 (1.08 to 6.5) |
| ≥18 years | 2.5 (1.6 to 3.9) | 2.3 (1.43 to 3.6) | 3.8 (1.99 to 7.2) | 3.1 (1.19 to 8.3) |
| Silica exposure from non-coal occupations only | 1.3 (1.1 to 1.7) | 1.2 (0.97 to 1.6) | 1.8 (1.19 to 2.7) | 2.7 (1.51 to 5.0) |
| Ergonomic hazard score (referent category=0 points) | | | | |
| 1 point | 1.5 (1.2 to 2.0) | 1.4 (1.08 to 1.9) | 2.4 (1.30 to 4.3) | 1.9 (0.77 to 4.5) |
| 2–3 points | 2.0 (1.5 to 2.5) | 1.8 (1.42 to 2.4) | 3.1 (1.85 to 5.2) | 2.4 (1.10 to 5.1) |
| 4–5 points | 2.6 (1.9 to 3.5) | 2.3 (1.67 to 3.1) | 5.5 (3.15 to 9.5) | 4.4 (1.97 to 9.6) |

All models shown in table control for the other variables shown in model plus age and smoking (never, former, current/recent). Sensitive RA case definition is based on report of doctor's diagnosis of RA, plus treatment with glucocorticoids. Specific RA case definition based on report of doctor's diagnosis of RA, plus treatment with disease modifying anti-rheumatic drugs. Models of RA exclude respondents who report arthritis not meeting the given definition, including general arthritis (n=759) but also RA not meeting the sensitive definition in that model (n=210) or RA not meeting the more specific definition (n=114).
RA, rheumatoid arthritis.

'beat knee').[15 16] In contrast, for RA, the potential for ergonomic risk is far less clear. It is possible that mechanical stressors lead to medical care for joint complaints diagnosed as RA. In that light, the blunted association that we observed between ergonomic factors and more narrowly defined RA raises the possibility, to date unstudied, that some of the association may be attributable to diagnostic imprecision.

The epidemiological relationship between cigarette smoking, past or current, and RA is complex. Based on observational data it even has been argued the active smoking may be protective against severity, a conclusion that may not sufficiently consider time varying confounding.[17] Analysing the relationship between occupation and smoking is similarly fraught with time varying confounding in the context of 'the healthy worker survivor effect.'[18] Thus, when taking into account the potential the concomitant effects of smoking, RA, and occupation, caution is certainly warranted. Although we did estimate greater silica-associated risk among former and lower duration smokers, which is somewhat counterintuitive, arguing for explanatory factors would be overly speculative.

Potential limitations in our study approach include a low response rate, reliance on self-reported diagnostic and treatment data, the lack of employment records or workplace inspection data, possible reporting bias, limited availability of potential confounding variables, and, for some of these analyses, the pooling of data from two separate surveys. Telephone surveys are typically characterised by low response rates, as in this study. Nonetheless, it would seem unlikely that this lack of response was systematic in a way that could explain the associations we observed nor do we have reason to believe that the recruited sample is unrepresentative of the underlying target population. Moreover, using RDD samples allows for a less-biased approach to occupational epidemiology studies than healthcare-based sampling and is less limited than workplace-based recruitment. Although we do not have physician confirmation of diagnosis in this analysis, the availability of DMARD information in the more specific definition serves to validate reported RA diagnosis. Because this study is not limited to a single worksite or occupational cohort, we do not have the possibility of workplace-specific data. This limitation is counterbalanced by the population-based survey approach we have taken. This makes possible the PAF estimate shown in figure 1, underscoring that not only are the odds of RA elevated, but that nearly one in two cases is linked to occupation. With self-report, recall bias is always a potential factor. There is no reason to suspect, however, that this mechanism explains the findings we observed. The brevity of the survey did not allow for ascertainment of all possibly relevant covariates, including body mass index and alcohol consumption,

both of which are believed to be associated with increased RA risk. For example, a recent metanalysis estimated that obesity was associated with an approximately 25% increased risk of RA, whereas ethanol consumption was modestly protective (an 8% reduction).[19] Although it is theoretically possible that the coal miners and other silica exposed persons in our study were more likely to be obese and less likely to drink ethanol than the non-exposed, such confounding would not explain the magnitude of effect we observed. For some of the analyses we combined data from two separate surveys. The parallel survey design carried out using the same methods and yielding remarkably similar variable prevalence supports this approach, as does the lack of difference in results from the sensitivity analysis using a GEE approach to account for any systematic differences between the two surveys.

In summary, this analysis supports and amplifies our previous findings of a strong association between coal mining and other silica-exposing dust trades in Appalachia and RA, taking into account age, smoking and occupational ergonomic risks, the latter being largely overlooked as a cofactor in work-related RA. These findings add to a growing body of literature on increased risk of RA associated not only with silica but other exposures as well, across a range of vocational factors.[20–27] In arthritis in general, but especially in RA, clinicians should consider occupational histories in the aetiology of disease, in both current and retired workers. As importantly, those considering attribution of disease from workers compensation and other social insurance perspectives, should recognise the strong link between coal mining and other silica exposure and RA.

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