Original Paper

Novel Occupational and Environmental Risk Factors for SARS-CoV-2 Infection Among Coal Miners: Longitudinal Cohort Study

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Abstract

Background: Miners are essential rural workers who may work in close proximity to others in inadequately ventilated environments and cannot telecommute or work flexible hours, rendering them vulnerable to SARS-CoV-2 transmission. Exposure to particulate air pollution may also be associated with an increased risk of SARS-CoV-2 infection and mortality. Chronic exposure to particulate matter causes overexpression of the alveolar angiotensin-converting enzyme 2 receptor, facilitating SARS-CoV-2 entry into lung epithelial cells.

Objective: We tested the hypothesis that coal miners with higher levels of self-reported particulate matter exposure assessed separately for occupational dust, residential wood burning, and shared transportation have a greater risk of SARS-CoV-2 infection than miners with lower exposure.

Methods: We conducted a longitudinal study from February 2021 to March 2022 involving 169 surface coal miners in New Mexico and 61 in Wyoming. Seropositivity was determined by measuring immunoglobulin G antibodies to the nucleocapsid protein of SARS-CoV-2 in plasma samples at baseline and at 3, 6, and 12 months after study enrollment. Predictor variables were self-reported exposure to occupational dust, wood burning, and shared transportation. The outcome variable was postbaseline incident seropositivity, defined as any new positive antibody result following enrollment during the 12-month study period. We used logistic regression and Firth-penalized likelihood for analysis; the multivariable model used the least absolute shrinkage and selection operator model selection method. Multivariable models were adjusted for sex, race and ethnicity, mine site (state), COVID-19 vaccination status, and baseline (prevalent) seropositivity.

Results: The study included 230 miners—44% (101/230) Hispanic and 13% (29/230) American Indian, mostly men (202/230, 88%), and 73% (169/230) from New Mexico and 27% (61/230) from Wyoming. At baseline, 23% (52/230) of participants reported COVID-19 vaccination; 25% (58/230) reported high baseline dust exposure, 18% (41/230) reported burning wood very often, and 23% (54/230) reported sharing transportation very often. Higher self-reported mining dust exposure was associated with lower odds of incident seroconversion, but the association was not significant after adjustment (adjusted odds ratio 0.42, 95% CI 0.17-1.07; *P*=.07). No incident seroconversions occurred among participants reporting frequent residential wood burning (0/35, 0%), and wood-burning frequency was not associated with incident seroconversion. Shared transportation frequency was also not associated with incident seroconversion.

Conclusions: Self-reported occupational dust exposure was not associated with higher odds of incident SARS-CoV-2 seroconversion in miners; point estimates instead suggested lower odds. This unexpected finding most likely reflects unmeasured workplace factors rather than a protective effect of dust; because individual respirator use and work microenvironment data were not collected, no causal inference can be drawn. Our results highlight the need for additional research on how occupational and environmental exposures interact with infectious disease dynamics in essential rural workforces.

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KEYWORDS

seroprevalence; shared transportation; COVID-19; transmission; particulate matter; surveillance; mining; dust; occupational exposure; wood smoke

Introduction

SARS-CoV-2, the virus that causes COVID-19, infects the epithelial cells of the respiratory tract [1]. It is believed that inhaled aerosol particles play a major role in viral pathogenesis [2]. Airborne particulate matter (PM) can impair mucociliary clearance, damage the epithelial barrier, and alter local immune responses [3-5]. The effects of chronic PM exposure may create conditions that facilitate viral entry into the lung [6]. A complete understanding of factors that increase the risk of SARS-CoV-2 infection is particularly important in occupations and communities where individuals are regularly exposed to PM.

Miners are essential rural workers who may work in close proximity to others in inadequately ventilated environments and cannot telecommute or work flexible hours, rendering them vulnerable to SARS-CoV-2 transmission [7]. Miners also face unique risks due to long-term occupational exposure to inhaled dust, which is known to adversely affect respiratory health [8]. A previous study has shown strong spatial associations between particulate pollution from mining and respiratory disease burden in quarry-adjacent communities [9]. Moreover, studies show that inhaled exposure to PM—particularly fine particles with a diameter of 2.5 µm or smaller (PM2.5)—increases susceptibility to influenza infection [10]. However, the risk of viral respiratory infection can vary depending on particle type and size, exposure location (outdoors vs indoors), and masking and ventilation conditions [11]. Despite these findings, viral transmission, including transmission of SARS-CoV-2, remains inadequately studied in miners.

Rural communities, where many mining operations are located, also face unique environmental hazards outside of work that increase exposure to PM. Residential wood burning, often used for heating, releases high amounts of fine PM [12]. This PM can penetrate deep into the lungs, increasing inflammation and oxidative stress [13]. Certain behaviors, such as participating in shared transportation, where a single car is shared by more than one traveler to remote job sites, may also raise the risk of viral transmission by increasing close contact in confined spaces for prolonged durations [14]. Despite these interconnected risk factors, few studies have examined how occupational dust exposure, household air pollution from residential wood burning, and shared transportation separately impact SARS-CoV-2 infection risk among essential workers in rural areas.

To address this critical gap in the literature, we conducted a longitudinal study of miners during the COVID-19 pandemic. The aim of the study was to determine whether occupational dust exposure, residential wood burning, and frequency of sharing transportation were independently associated with postbaseline incident SARS-CoV-2 infection. Understanding how these environmental and occupational factors interact is vital for developing effective strategies to prevent respiratory viral diseases in rural work settings and for protecting essential workers exposed to potential risks, both at work and at home, during viral outbreaks.

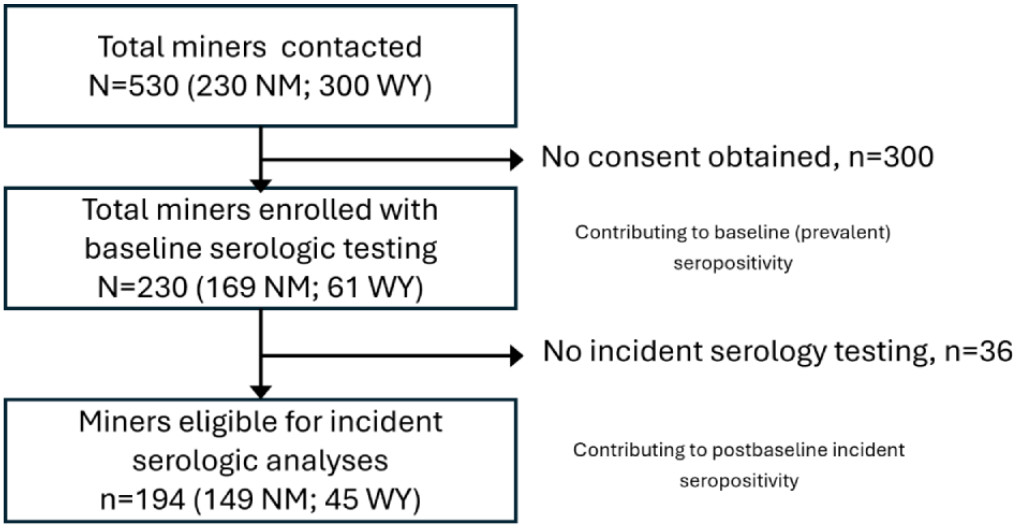
Methods

Study Design and Setting

From February 2021 to March 2022, we conducted a longitudinal surveillance study of miners employed at 2 rural surface coal mines operated by the same company in Campbell County, Wyoming (300 miners employed, of whom 61 were recruited) and McKinley County, New Mexico (230 miners employed, of whom 169 were recruited; Figure 1). The main reason for refusal to participate was participants' unwillingness to consent to filling out the questionnaire and/or to provide biological samples. Both surface coal mines had similar engineering, administrative, and personal protective controls in place. Both sites conducted daily SARS-CoV-2 symptom and fever screening and required the use of face masks on-site as part of standard mine safety operations during the COVID-19 pandemic. Workplace policy at both sites precluded miners with COVID-19 symptoms from reporting for duty. The New Mexico site also implemented frequent point-of-care molecular workplace testing on self-administered nasal swabs for workers [15]. Inclusion criteria were as follows: male or female miners currently employed at the abovementioned mines, aged at least 18 years, willing and able to consent to study participation, and willing and able to comply with study procedures. Exclusion criteria were as follows: unable or unwilling to consent and aged <18 years.

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Figure 1. Flow diagram of study participants. NM: New Mexico; WY: Wyoming.



Study Procedure

At the start of the study, all workers self-reported demographic and exposure information. At the start of each work shift, trained mine safety personnel collected a 24-hour history of SARS-CoV-2 symptoms and the health care professional's diagnosis of infection. Temperature was measured using a forehead thermometer. At the start of every alternate work shift, staff at the New Mexico site collected a self-administered nasal swab from each participating worker for point-of-care surveillance testing for the SARS-CoV-2 antigen, as described in detail in our previous report [15]. Surveillance on alternating shifts was chosen to balance practical considerations, costs, and test availability. Positive surveillance test results were confirmed by reverse transcription polymerase chain reaction and followed by isolation and health care professional referral, consistent with the US Centers for Disease Control and Prevention guidance [15].

Venipuncture blood samples of 8 mL were collected at baseline and at 3, 6, and 12 months from all participants to measure SARS-CoV-2 serological outcomes. These longitudinal sampling intervals were chosen to characterize and evaluate the natural history of SARS-CoV-2 infections across the study cohorts, given the stability of seroconversion status in 3 to 6 months [16,17]. Venipuncture blood was centrifuged at the mine site, and plasma was aspirated, aliquoted, and frozen by trained nurse technicians. Plasma samples were tested to determine the seroprevalence of COVID-19 using the immunoglobulin G antibody to the nucleocapsid protein of SARS-CoV-2. Tests were performed using a qualitative chemiluminescent immunoassay (ARUP Laboratory) under the Emergency Use Authorization. Unlike antibodies to the spike protein, antibodies to the nucleocapsid protein develop in response to natural infection and not due to COVID-19 vaccination. The assay demonstrated a reported sensitivity of 100% in samples collected 14 days or more after symptom onset and a specificity of 99.6% [18].

Data were transferred manually by the miner coinvestigators to the university-based investigators, who entered the information into a secure REDCap (Vanderbilt University) database. All information entered was double-checked for accuracy.

Variables

Predictor Variables

The primary predictor variable was occupational dust intensity. Additional predictors of interest were frequency of shared transportation (ie, carpooling) and exposure to residential wood smoke.

Information on occupational dust exposure intensity was assessed using a job-exposure matrix developed through consensus with a senior mine safety officer at each participating mine. Each safety officer had more than 2 decades of experience measuring and monitoring dust exposure across a range of mine job sites and roles. Miners self-reported their primary job site and role at enrollment. All miners worked 12-hour shifts on a 4-days-on, 4-days-off schedule. Because job site and role assignments and shift schedules remained stable throughout the study period, mine safety officers used the reported job site and role to assign dust exposure intensity estimates using the job-exposure matrix (Multimedia Appendix 1) for the duration of follow-up. The original dust rating scale ranged from 1 to 13 in intensity and was rescaled to 1 to 10. Occupational dust intensity was studied both as a categorical variable (low vs high, based on the mean dust intensity score) and a continuous variable in alternative analyses.

Frequency of shared transportation was measured through the questionnaire as the reported frequency of driving shared vehicles to or from work with other miners, using the response categories never, rarely, or sometimes; often; and very often. The question in the questionnaire (Multimedia Appendix 2) was worded as follows: "How often do you share a ride to and from the mine with another person who does not reside in your house?"

Residential wood burning was measured through the questionnaire using the same scale to capture the frequency of home heating–related particulate exposure. The question in the questionnaire (Multimedia Appendix 2) was worded as follows: "How frequently do you burn wood in your house during the

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most recent cold temperature season?" The response options were never, rarely every few months, occasionally every month, and frequently every week.

Several covariates were self-reported and included sex, race and ethnicity, mine site (ie, New Mexico or Wyoming), and COVID-19 vaccination status, which were collected through the baseline questionnaire. The COVID-19–related questions were taken from the standard questionnaire sets in the PhenX COVID-19 library and cannot be considered broadly validated [19]. The questionnaire was self-administered by study participants but reviewed for quality by trained mine safety personnel.

Outcome Variable

The outcome, a binary categorical variable, was postbaseline incident seropositivity, defined as any new positive antibody result following enrollment during the 12-month study period, that is, seronegative at enrollment with seroconversion during the study period.

Statistical Analysis

Descriptive statistics were used to summarize miner characteristics and exposures. Characteristics of miners with low vs high occupational dust exposure were summarized as frequencies and percentages. Frequencies of categorical variables for the 2 groups were compared using χ^2 tests and Fisher exact tests.

Analyses separately focused on 3 predictor variables (occupational dust exposure, residential wood burning, and shared transportation) and their respective relationships with the outcome. The associations between predictor and outcome variables were evaluated using logistic regression models. We used the Firth penalized likelihood technique to address 0-event cells and reduce small-sample bias during logistic regression modeling [20]. For multivariable models, the least absolute shrinkage and selection operator model selection method [21] was used to improve model parsimony and reduce overfitting. Potential confounders, each coded as dummy variables, included race and ethnicity; mine site (state of employment: New Mexico or Wyoming); COVID-19 vaccination status; and baseline (prevalent) seropositivity, defined as a positive antibody result at enrollment. Although some covariates, such as COVID-19 vaccination status, were not strictly confounders but independent predictors of the outcome, we included them in the multivariable analyses to account for their potential effects. Odds ratios (ORs) and 95% CIs were computed to describe association strength. SAS (version 9.4; SAS Institute Inc) was used for statistical analyses, and a *P* value of less than .05 was considered statistically significant. With a sample size of 230, our estimated statistical power for a 2-group comparison of seropositivity was at least 80% if the groups differed by at least 21%.

The overall missing rates for predictor variables were all below the cutoff point of 5%. Given the low proportion of missing data, complete case analysis was used [22].

Ethical Considerations

The University of New Mexico Health Sciences Center's Human Research Protections Office (HRPO 20-680), our institutional review board, approved the study. All participants provided informed consent and could opt out. Participant privacy and confidentiality were protected during the study. The data were deidentified for analysis. Participants were compensated with a US $10 electronic merchandise card for each specimen and survey collected.

Results

Demographic Characteristics

A total of 230 miners were studied, including 169 (73.5%) from New Mexico and 61 (26.5%) from Wyoming. At baseline, COVID-19 vaccination was reported by 22.6% (n=52) of participants; 25.2% (n=58) of participants reported high baseline dust exposure, 17.8% (n=41) reported burning wood very often, and 23.5% (n=54) reported sharing transportation very often.

The mean self-reported dust exposure intensity score was 3.49 (SD 2.18), and the median was 3.0 (IQR 2.0-5.0). There were no differences in demographic characteristics between the dust exposure groups, except for a greater frequency of men in the high–dust-exposure group than in the low–dust-exposure group (Table 1). SARS-CoV-2 baseline (prevalent) seropositivity status upon study enrollment was not associated with dust exposure (Table 1).

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Table 1. Participant demographics by self-reported baseline coal mine dust exposure level, defined by the mean dust exposure score (N=230).

Characteristics	Dust exposure, n (%)		*P* value
	Low (n=172)	High (n=58)	
State			.06
Wyoming	51 (29.7)	10 (17.2)	
New Mexico	121 (70.3)	48 (82.8)	
Sex			.047
Male	145 (84.3)	57 (98.3)	
Female	24 (14.0)	1 (1.7)	
Other	2 (1.2)	0 (0)	
Missing	1 (0.58)	0 (0)	
Race			.41
American Indian or Alaska Native	20 (11.6)	9 (15.5)	
White	114 (66.3)	38 (65.5)	
Other	31 (18.0)	9 (15.5)	
Missing	7 (4.1)	2 (3.5)	
Ethnicity			.98
Hispanic	75 (43.6)	26 (44.8)	
Not Hispanic	88 (51.2)	29 (50.0)	
Missing or other	9 (5.2)	3 (5.2)	
Annual household income (US $)			.10
<15,000	1 (0.58)	0 (0)	
15,000-59,999	7 (4.1)	8 (13.8)	
60,000-79,999	33 (19.2)	13 (22.4)	
80,000-99,999	35 (20.4)	12 (20.7)	
≥100,000	48 (27.9)	16 (27.6)	
Other	44 (25.6)	7 (12.1)	
Missing	4 (2.3)	2 (3.5)	
Education			.57
Less than 12th grade	7 (4.1)	4 (6.9)	
High school graduate or GED[a] completed	70 (40.7)	22 (37.9)	
College or other advanced degree	89 (51.7)	32 (55.2)	
Missing or other	6 (3.5)	0 (0)	
Age (years)			.73
<40	59 (34.3)	23 (39.7)	
40-59	92 (53.5)	30 (51.7)	
60-74	19 (11.1)	5 (8.6)	
Missing	2 (1.2)	0 (0)	
COVID-19 vaccination			.08
No	124 (72.1)	50 (86.2)	
Yes	45 (26.2)	7 (12.1)	
Missing	3 (1.7)	1 (1.7)	
Burning wood frequency			.18
Never, rarely, or sometimes	135 (78.5)	42 (72.4)	

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Characteristics	Dust exposure, n (%)		*P* value
	Low (n=172)	High (n=58)	
Often	3 (1.7)	2 (3.5)	
Very often	27 (15.7)	14 (24.1)	
Missing	7 (4.1)	0 (0)	
Transportation sharing frequency			.83
Never, rarely, or sometimes	106 (61.6)	36 (62.1)	
Often	22 (12.8)	5 (8.6)	
Very often	39 (22.7)	15 (25.9)	
Missing	5 (2.9)	2 (3.5)	
Self-reported COVID-19 infection			.24
Negative	114 (66.3)	37 (63.8)	
Positive	34 (19.8)	8 (13.8)	
Missing	24 (14.0)	13 (22.4)	
Baseline (prevalent) seropositivity			.20
Negative	142 (73.2)	52 (26.8)	
Positive	30 (83.3)	6 (16.7)	

[a]GED: General Educational Development test (a high school equivalency test).

Postbaseline Incident Seropositivity

Lower postbaseline incident seropositivity was associated with greater dust exposure (unadjusted OR 0.39, 95% CI 0.16-0.92; *P*=.03; Table 2). This association was not significant in the adjusted model. The frequencies of residential wood burning and carpooling were not significantly associated with postbaseline incident seropositivity (Tables 3 and 4, respectively).

Table 2. Association of self-reported coal mine dust exposure (as a categorical variable) with postbaseline incident seropositivity (outcome; N=230)[a].

Frequency of exposure	Positive, n (%)	Univariate model		Multivariable model	
		OR[b] (95% CI)	*P* value	OR (95% CI)	*P* value
Low (n=142)	30 (21.1)	Reference	Reference	Reference	Reference
High (n=52)	3 (5.8)	0.39 (0.16-0.92)	.03	0.42 (0.17-1.07)	.07

[a]The multivariable model, using the least absolute shrinkage and selection operator model selection method, retained the following covariates: sex; race and ethnicity; mine site (state of employment: New Mexico or Wyoming); COVID-19 vaccination status; and baseline (prevalent) seropositivity, defined as a positive antibody result at enrollment. Similar results were obtained when dust was used as a continuous variable.

[b]OR: odds ratio.

Table 3. Associations of self-reported residential wood burning (as a categorical variable) with postbaseline incident seropositivity (outcome; N=230)[a].

Frequency of exposure	Positive, n (%)	Univariate model		Multivariable model	
		OR[b] (95% CI)	*P* value	OR (95% CI)	*P* value
Never, rarely, or sometimes (n=155)	32 (20.7)	Reference	Reference	Reference	Reference
Often (n=4)	0 (0)	1.10 (.14-8.55)	.70	0.89 (0.08-10.85)	.73
Very often (n=31)	0 (0)	0.72 (0.30-1.71)	.70	0.63 (0.22-1.87)	.73

[a]Firth-penalized logistic regression was used for univariate and multivariable analyses because 0 prospective incident cases occurred in the higher wood-burning groups. Results from the exact logistic regression were consistent with those of the Firth analysis. The multivariable model, using the least absolute shrinkage and selection operator model selection method, retained the following covariates: sex; race and ethnicity; mine site (state of employment: New Mexico or Wyoming); COVID-19 vaccination status; and baseline (prevalent) seropositivity, defined as a positive antibody result at enrollment.

[b]OR: odds ratio.

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Table 4. Associations of shared transportation frequency (as a categorical variable) with postbaseline incident seropositivity (outcome; N=230)[a].

Frequency	Positive, n (%)	Univariate model		Multivariable model	
		OR[b] (95% CI)	*P* value	OR (95% CI)	*P* value
Never, rarely, or sometimes (n=119)	21 (17.7)	Reference	Reference	Reference	Reference
Often (n=22)	4 (18.2)	1.11 (0.43-2.86)	.67	2.65 (0.88-8.01)	.20
Very often (n=49)	8 (16.3)	0.72 (0.33-1.59)	.67	1.53 (0.60-3.91)	.20

[a]The multivariable model, using the least absolute shrinkage and selection operator model selection method, retained the following covariates: sex; race and ethnicity; mine site (state of employment: New Mexico or Wyoming); COVID-19 vaccination status; and baseline (prevalent) seropositivity, defined as a positive antibody result at enrollment.

[b]OR: odds ratio.

Discussion

Principal Findings

In this longitudinal cohort of surface coal miners in New Mexico and Wyoming, self-reported occupational dust exposure was associated with lower odds of incident seroconversion, although this association was not statistically significant after adjustment. Residential wood burning was not associated with incident seroconversion. Shared transportation was also not associated with incident SARS-CoV-2 infection. These findings indicate that environmental and occupational factors may not consistently affect the risk of SARS-CoV-2 infection in this cohort of rural essential workers.

Exposure to PM has been related to new cases and clinical severity of SARS-CoV-2 infections in the published literature, suggesting that PM may be a vector for viral transmission or generate oxidative stress and inflammatory responses associated with viral infection [23-27]. Therefore, we expected a positive association between occupational dust exposure and SARS-CoV-2 infection but unexpectedly found a nonsignificant inverse adjusted association with incident seroconversion in our cohort of miners. This finding appears biologically counterintuitive, as several lines of evidence suggest that particulate exposures may increase susceptibility to COVID-19. For example, a large US cohort study reported that higher historical PM2.5 exposure was significantly associated with increased county-level COVID-19 death rates after adjustment for multiple confounders [28]. Similarly, PM2.5 exposure was a significant risk factor for COVID-19 infection in low- and middle-income Asian countries [29]. Moreover, experimental studies reveal that inhaled PM enhances the expression of angiotensin-converting enzyme 2 and transmembrane protease serine 2, facilitators of SARS-CoV-2 entry into airway epithelial cells [30,31]. Exposure to mineral and silica dust, prevalent in mining environments, has long been known to impair macrophage function and increase susceptibility to respiratory infections [8,32]. The inverse association in our study most likely reflects unmeasured workplace confounding rather than a protective effect of dust. Miners in dustier roles may be more likely to wear respirators (N95 filtering facepiece respirators); to operate haul trucks and other heavy equipment from enclosed, filtered cabs; or to work alone or outdoors; each of these would reduce opportunities for person-to-person SARS-CoV-2 transmission regardless of dust exposure. Because we did not collect data on individual respirator use or personal protective equipment compliance, equipment cab enclosure and filtration, or other work microenvironment characteristics, we could not evaluate these explanations, and our findings do not permit any causal interpretation. Health-related selection into or out of high-dust jobs (the “healthy worker effect”) may also contribute [33]; however, we did not collect data on job tenure, prior job transitions, or health status at job assignment, so this explanation remains speculative and less likely. Differential access to or use of SARS-CoV-2 testing outside the workplace by population subgroups may also have influenced our observed seropositivity patterns and differential ascertainment of infection [34].

We found no association between residential wood burning and incident seroconversion; no incident seroconversions occurred among the 35 participants who reported burning wood often or very often (0/4 and 0/31, respectively). This finding contrasts with population-based studies showing that wood smoke PM2.5 exposure is associated with increased COVID-19 incidence, severity, and mortality [35,36] and with experimental evidence that household air pollution from wood combustion can impair mucociliary clearance and respiratory defense [13,37]. However, the small number of participants in the frequent wood-burning categories limited our ability to detect an association, and our results neither support nor exclude residential wood smoke as a risk factor for SARS-CoV-2.

We found no significant associations between shared transportation and seropositivity. Shared transportation has been implicated in transmission in other occupational settings. Evidence from large urban transit systems shows that closed, crowded transport can facilitate SARS-CoV-2 transmission. For instance, studies from New York City found that neighborhoods with higher subway use saw higher COVID-19 rates and mortality [38,39]. Other studies suggest that poor ventilation in shared vehicles raises aerosol buildup and transmission risk [40]. The lack of a significant association in our study suggests that shared transportation in rural settings, such as consistent passenger groups, open-window ventilation, adherence to mask guidelines, and the possibility of symptomatic or infected miners voluntarily reducing their use of shared transportation, may have reduced the potential for transmission compared with crowded public transport settings.

The strengths of our study include its prospective design, multiple serological tests, assessment of both home and

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workplace exposures, a study population of rural essential workers, and robust participation by racial and ethnic minority groups. In addition, participation took place during active mining operations, providing real-world applicability during the pandemic. A major limitation is reliance on self-reported, nonvalidated exposure measures (eg, the job-exposure matrix), which are subject to measurement error and recall bias, compared with objective environmental monitoring; this bias is estimated to be nondifferential. Other limitations include potential residual confounding by unmeasured workplace-specific factors (eg, ventilation quality, respirator and mask use and adherence, work in enclosed equipment cabs, indoor vs outdoor work, and shift patterns) and personal factors (eg, socioeconomic status, housing quality, and household density). Additionally, small subgroup sizes, particularly for frequent wood burning and shared transportation, may have limited statistical power and increased the risk of type II error. In particular, no incident seroconversions occurred among participants reporting frequent wood burning, precluding estimation of prospective associations for this exposure. Furthermore, not adjusting for multiple comparisons may increase type I error; this adjustment would have required an α value of .017 (.05/3) for the 3 predictor variables. The associations described in our study findings do not imply causal relationships and should be interpreted cautiously. Declining antinucleocapsid antibody levels over time may also have affected the detection of past infections, with underascertainment of cases contributing to misclassification bias. Studies report a median seroreversion time of approximately 8 months and substantial declines in detectability within the first year after infection [16,17]. Because the study spanned 12 months, seroreversion could differentially affect detection across exposure groups if infection timing varied, introducing potential differential misclassification bias. Given these limitations, the study findings should be considered preliminary, and additional confirmation may be helpful to establish internal and external validity.

Future studies should incorporate objective environmental monitoring (particulate sensors), viral genomic analyses, and larger sample sizes across multiple mining sectors. In addition, further research should examine behavioral factors, household ventilation, and specific workplace practices to understand the pathways of risk better. Exploring how environmental exposures interact with infectious disease dynamics may help develop targeted interventions for essential rural workforces.

Conclusions

In conclusion, increased occupational dust exposure may be associated with lower postbaseline incident seropositivity among miners. These results highlight the need to consider both occupational and household environmental exposures in pandemic response planning and underline the importance of ongoing research to improve respiratory protection strategies for rural mining communities. The implications of our findings extend beyond this study, providing valuable insights for designing interventions to maintain employees' safety in other essential workplaces during outbreaks of viral respiratory pathogens.

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Data Availability

All research data are available from the authors upon request, subject to institutional review board approval.

Generative AI Use

The authors declare that generative AI was not used in the preparation of this manuscript.

Authors' Contributions

THK, AS, XWS, and OBM made substantial contributions to the conception or design of the work. AS and OM contributed to data acquisition, and AS, XWS, and OBM contributed to data analysis. THK, AS, XWS, and OBM contributed to the interpretation of the data. All authors contributed to drafting the work or reviewing it critically for important intellectual content and gave final approval of the version to be published. All authors agreed to be accountable for all aspects of the work and to ensure that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflicts of Interest

None declared.

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Multimedia Appendix 1

Dust exposure intensity measure using the job-exposure matrix.
[DOCX File , 21 KB-Multimedia Appendix 1]

Multimedia Appendix 2

Baseline questionnaire.
[PDF File (Adobe PDF File), 155 KB-Multimedia Appendix 2]

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Abbreviations

OR: odds ratio
PM: particulate matter
PM2.5: particulate matter with a diameter of 2.5 μm or smaller

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