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REVIEW

A systematic review of occupational exposure to respirable coal mine dust (RCMD) in the U.S. mining industry

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Abstract

Cumulative inhalation of respirable coal mine dust (RCMD) can lead to severe lung diseases, including coal worker's pneumoconiosis (CWP), silicosis, mixed dust pneumoconiosis, dust-related diffuse fibrosis (DDF), and progressive massive fibrosis (PMF). Statistics from the number of reported cases showed a significant decrease in the progression of respiratory diseases in the 1990s. However, an unexpected increase in the number of CWP cases was reported in the late 1990s. To date, there has been no comprehensive systematic review to assess all contributing factors to the resurgence of CWP cases. This study aims to investigate the effects of various mining parameters on the prevalence of CWP in coal mines. A systematic review using the preferred reporting items for systematic reviews and meta-analysis (PRISMA) method was conducted to investigate the health effects of RCMD exposure and identify the factors that may contribute to the recent resurgence of CWP cases. The systematic review yielded a total of 401 papers, which were added to the database. The total number of 148 and 208 papers were excluded from the database in the process of screening and eligibility, respectively. Then, 18 papers were considered for data selection and full-text assessment. The review revealed that factors including geographic location, mine size, mining operation type, coal-seam thickness, coal rank, changes in mining practices, technology advancement, and engineering dust control practices are contributing to the recent resurgence of CWP among coal workers. However, the evidence for root causes is limited owing to the methodological constraints of the studies; therefore, further detailed studies are needed.

Keywords Respirable coal mine dust · Systematic review · Coal worker's pneumoconiosis · Respiratory diseases · Exposure limit · Occupational exposure

1 Introduction

Respirable coal mine dust (RCMD) is a mixture of more than 50 elements and their oxides. It is estimated that 40%–95% of respirable dust in the underground coal mine is pure coal, and the rest contains particles originated from cutting roof and floor rock, diesel exhaust from equipment, and rock dusting (Walton et al. 1977; NIOSH 1995). Cumulative inhalation of RCMD can lead to severe lung diseases, including coal worker's pneumoconiosis (CWP), silicosis, mixed dust pneumoconiosis, dust-related diffuse fibrosis (DDF), and progressive massive fibrosis (PMF) (Cullinan et al. 2017; Hall et al. 2019). In the United States, an unexpected and severe increase in coal miners' lung diseases in the late 1990s prompted researchers to investigate the causes of the disease resurgence.

Several potential reasons have been hypothesized for the increased rate of CWP among U.S. coal miners, including geological factors (e.g., Laney et al. 2010; Blackley et al. 2014), thin-seam mining (e.g., Antao et al. 2006; Sarver et al. 2019), quartz exposure (e.g., Sarver et al. 2020), coal rank (e.g., Laney and Attfield 2010; Pollock et al. 2010), and mine size (e.g., Blackley et al. 2014; Gamble et al. 2011). However, there has been no comprehensive systematic review investigating the role of all potential contributing factors.

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Systematic review is a type of review that uses explicit and systematic methods to collect reliable data from all available databases to reduce random and systematic errors of bias; thus, providing reliable findings to draw conclusions, and make decisions (Torgerson 2003). Systematic review is a technically robust methodology for summarizing and testing the consistency of the primary studies in a given topic. In conducting a systematic review, all available evidence, whether they support or refute a hypothesis, are included. Therefore, the rejection or confirmation of a hypothesis is with fewer biases compared to other types of review (Shekarian and Mellat-Parast 2020).

A few researchers investigated some aspects of occupational exposure to RCMD. Beer et al. (2017) conducted a systematic review of the coal dust exposure to investigate whether the prevalence of occupational lung diseases is pure coal or coal mixed with silica minerals. In their study, a total of 2945 papers were collected, and nine papers were selected for evaluation of the topic by excluding the nonrelated articles. The study found that the evidence is limited for causal links between exposure to pure coal powder and lung diseases and suggested conducting further analysis of the data related to miners exposed to either pure coal or coal with very low minerals content. Jenkins et al. (2013) conducted a systematic review based on 34 selected articles to examine the links between coal dust exposure and cancer incidence and mortality. The study concluded that the available data are too limited to draw any final conclusions concerning a population cancer risk from coal mining.

Currently, there is no comprehensive systematic review on RCMD health effects in the U.S. This study aims to conduct a systematic review of RCMD exposure and investigate the impacts of mining parameters, including mine size, coal rank, geographical location, and coal seam thickness on the prevalence of CWP. The systematic review was performed based on the defined review protocol and then irrelevant papers were excluded. A total number of 401 publications were included in conducting this systematic review. The preferred reporting items for systematic reviews and meta-analysis (PRISMA) method was used and 18 articles were selected for data evaluation. A detailed discussion of the current state of knowledge on the potential role of mining parameters in the prevalence of CWP was provided. Furthermore, characterization of the selected studies, and the knowledge gaps were identified. The systematic review yields information on the role of various mining factors contributing to the coal mine disease. The information will be used to develop hypotheses during the statistical analysis of RCMD occupational health outcomes.

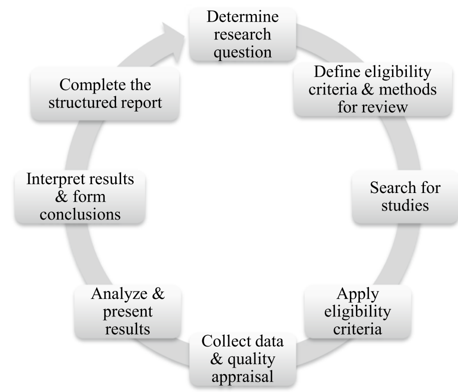

Fig. 1 The steps for conducting a systematic review. (Adapted from Tsafnat et al. 2014)

2 Materials and methods

A systematic review was conducted to investigate the contributing factors in recent resurgence of CWP among US coal miners. The steps for conducting a systematic review are shown in Fig. 1, and were followed in this study. Determination of an appropriate research question in early stages of a systematic review reduces the time and cost in identifying and studying relevant publications (Torgerson 2003). In this study, the following research questions were identified:

(1) What are the potential contributing factors in the resurgence of CWP among the US coal miners at the end of the 1990s?
(2) What is the current state of knowledge in RCMD exposure health risk?
(3) What are the knowledge gaps that future research should address?

The inclusion and exclusion criteria are rigorously and transparently reported in a high-quality systematic analysis. Eligible criteria are defined to reduce the reviewer's selection and inclusion bias in conducting the review. The protocol defines a set of pre-determined written conditions for inclusion and exclusion of studies. For example, the inclusion and exclusion may include a specific type of review, publication period and language, experiments carried on using a real experimental design, or other types of criteria related to the research questions. In this research, the eligibility criteria were defined in Table 1.

For this research, the systematic search for studies was initiated from various electronic databases such as PubMed, ScienceDirect, and Google Scholar. The keywords used for

Table 1 Inclusion and exclusion criteria for RCMD systematic review

Topic	Inclusion	Exclusion
Study topic	Articles related to respirable coal mine dust	Articles related to coal dust explosion
Study type	Different types of research (e.g., theoretical/conceptual, modeling/ simulation, case study, review, survey, etc.)	Commentary articles
Publication period	Articles published during 1950–2020	Published articles before 1950
Language	Publication in English	Studies written in non-English language
Publication reputation	Peer-reviewed articles	Non-peer-reviewed articles
Population of interest	Studies focused on coal workers	Studies related to non-coal workers or non-mining workers
Country of interest	Studies conducted in the U.S.	Studies conducted outside of the U.S.
Outcome	Occupational accidents/injuries Work-related to lung diseases such as CWP Contributing factors related to lung diseases	Outcomes with no relevance to lung diseases

collecting research articles included coal, respirable coal mine dust, coal dust characteristics, exposure limits and regulations, respiratory diseases, occupational health regulation, RCMD exposure, miners lung, black lung disease, lung deposition, CWP, silicosis, anthracosis, anthracosilicosis, interstitial lung disease (ILD), lung deposition, respiratory system, systematic review, occupational exposure, mine size, seam height, underground coal mining, accident analysis, occupational lung diseases.

The database was set by PRISMA method. Briefly, in this method, duplicate articles are removed, and at least two independent reviewers screened the search results. Screening is conducted based on titles and abstracts (first screening) and then by complete articles (second screening) to ensure that the articles meet the eligibility criteria. Following the identification of relevant publications, data must be retrieved using a standard data extraction form by at least two independent researchers (double data extraction). The studies are also evaluated in order to establish their quality (quality appraisal). Those publications that met the criteria and have the key features of the application (e.g., explicit rigorous protocol, summarized table, statistical analysis) are considered as *high-quality* articles. The data from those publications are then extracted and summarized in a synthesis. If the data is not in a format that allows a statistical summary, this can be done as a 'qualitative' overview. Statistical analysis can be performed if the data is numerical and homogeneous enough. Finally, the synthesis data will be analyzed in a report that will be subjected to peer review before publishing (Torgerson 2003).

In this research, a total of 401 articles were collected from the computer-based literature search. Upon excluding duplicate publications, the database included 372 articles. The titles were independently screened by two researchers against the inclusion criterion (Table 1). Furthermore, the references in each paper were examined to identify additional publications, which did not appear in the original literature search (snowballing). In the next step, the titles and abstracts were screened and 148 papers were excluded from the database. Afterward, full-text screening was performed on the remaining 224 publications. A total number of 204 papers were eliminated from the database by reviewing the outlines, objectives, conclusions, and health outcomes related to RCMD. Finally, using the inclusion and exclusion criteria, a total of 18 articles (16 from the aforementioned stages and 2 from snowball search) were considered for the systematic review. The inclusion process is presented as a flowchart in Fig. 2. The information extracted from selected papers, including authors, data sources, study period, number of data, geographic location, type of analysis, research category, results, conclusions, and recommendations, were provided in Table 2.

In this research, a comprehensive database was created, and the publications were categorized according to the project outline and the publication year (Fig. 3a and b). The categories include RCMD characteristics, health-diseases, dust control, respiratory deposition, mining methods, monitoring techniques, RCMD sources, standard and regulations, and systematic review. As shown in Fig. 3b, the majority of the selected articles were related to lung deposition (24%), health–diseases (23%), regulation-exposure (19%), and a very few studies were systematic review articles (3%).

3 Results and discussion

The summary of the papers selected for the systematic review data selection is listed in Table 2. The systematic review conducted in this research included a total of 401 publications. The majority of the selected articles were related to lung deposition, health-disease, and regulation-exposure. Irrelevant publications were excluded from the

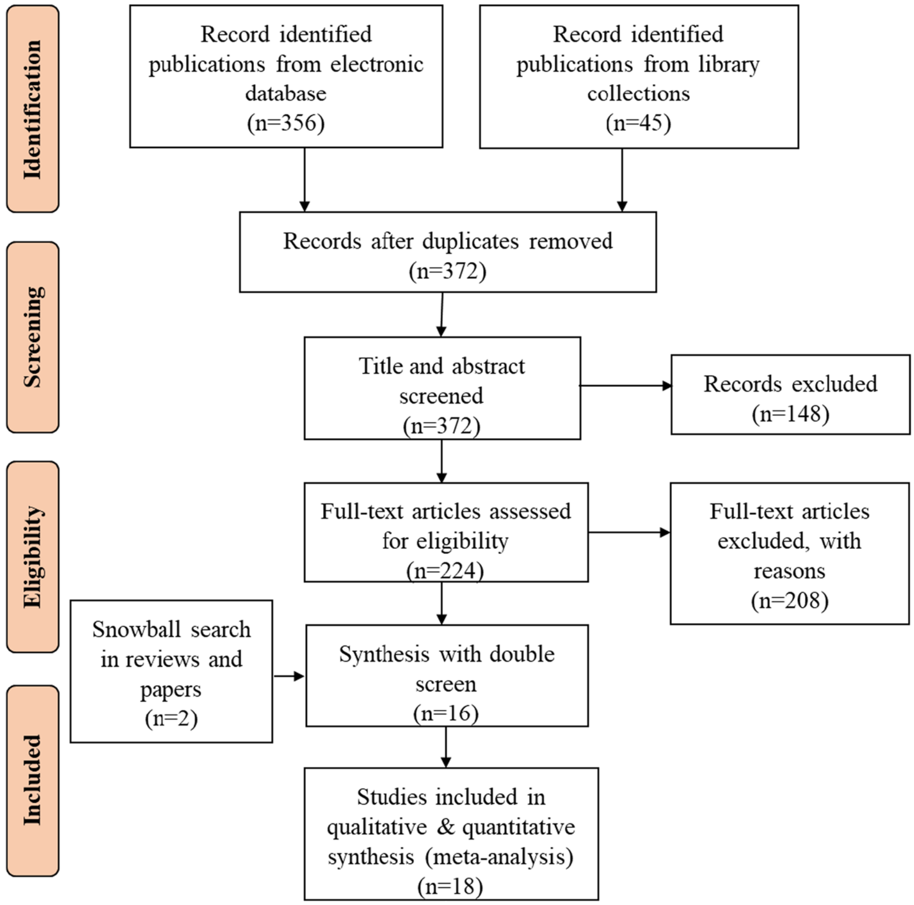

Fig. 2 Results of systematic review search (adapted from Moher et al. 2009)

database based on the inclusion and exclusion criteria (Table 1). Upon screening, a total number of 18 papers were selected to extract reliable quantitative and qualitative information for the systematic review. Individual factors, changes in mining practices, technology advancement, thin seam mining, mine size, coal rank, geographic location, mining method, rock dusting, and new cutting technology were among the parameters that were considered to potentially contribute to the resurgence of CWP.

In the majority of the studies, exposure measurements were taken by gravimetric dust sampling or personal sampling instrument, and expressed as average mean exposure (mg/m^3). In two comprehensive studies for the U.S. underground and surface coal mines, 5.5% and 1.5% of RCMD samples in underground and surface mines, respectively, exceeded the permissible exposure limit (PEL) of 2.0 mg/m^3 (Doney et al. 2019a, b). In those studies, 15.3% of surface silica samples and 2.0% of underground silica samples exceeded the PEL. In comparison to the rest of the United States, Central Appalachia exhibited statistically greater RCMD, respirable quartz, and precent quartz in the samples. Over 32% of quartz samples exceeded the PEL in the drilling occupations. The arithmetic mean of respirable quartz for drilling occupations was 0.15 mg/m^3, approximately three times higher than the overall average (0.04 mg/m^3). Duration of RCMD exposure was in the range of 5–60 years of employment. In several studies, the duration of the dust exposure was not stated (Morgan et al. 1973; Laney et al. 2010; Vallyathan et al. 2011; Blackley et al. 2014; Hall et al. 2019, 2020; Sarver et al. 2020). Studies population was in the range of 4491 to 90,973 miners. Most studies' research populations were entirely male. As a result, the assessment contains no information concerning the specific risks of these exposures for females. There is only one study that includes females in the risk associated with coal mining (Jenkins et al. 2013). Due to the small sample size, those female miners were excluded from the study (Graber et al. 2017). There was no study focusing on the effect of pure respirable coal or silica on health (Beer et al. 2017). The focus of many studies was on Appalachian underground coal mines in Pennsylvania, Kentucky, Virginia, and West Virginia. Characterization of RCMD samples from the various geographic locations in the U.S. was performed in two different studies (Morgan

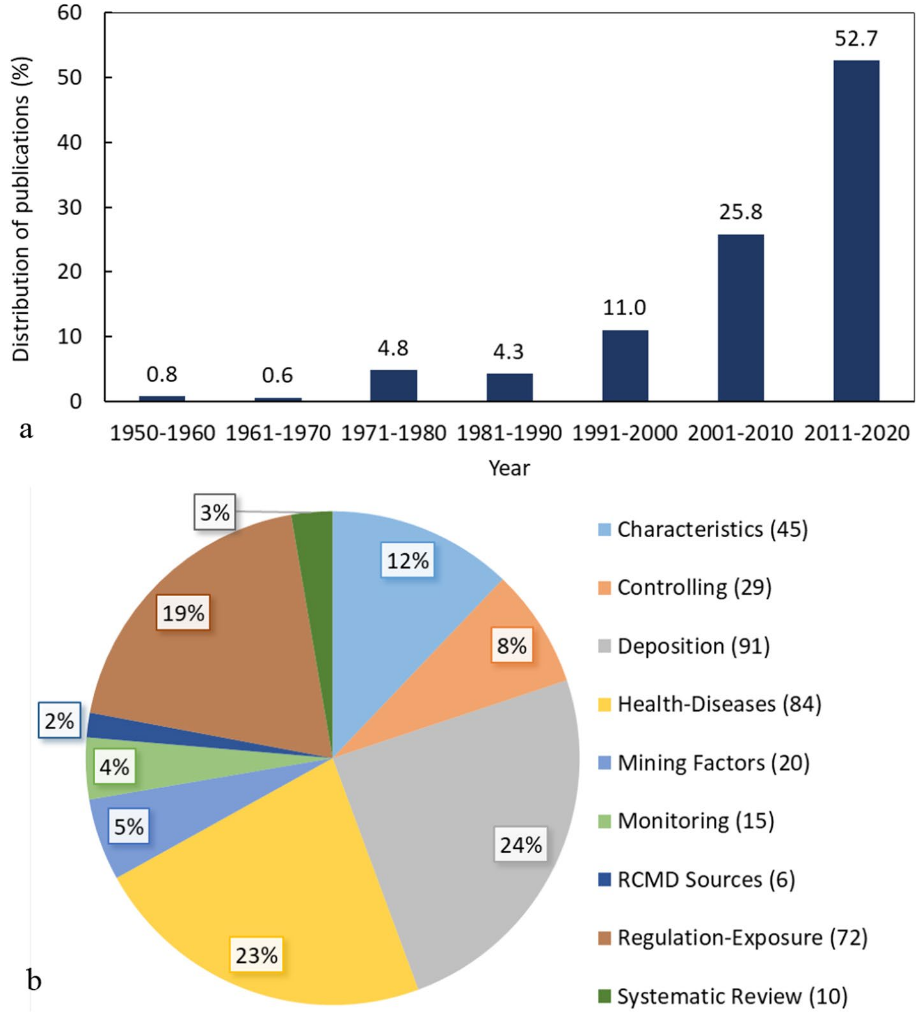

Fig. 3 **a** Distribution of publications by decades **b** Categories of the RCMD publication database (total number of 372 papers)

et al. 1973; Sarver et al. 2020). Due to the geographical clustering of coal mines in the U.S., regional variations in dust characteristics exist, which is associated with various lung diseases. In Central Appalachia, for instance, mines may have more rock strata sourced dust than in other mines in the United States (Sarver et al. 2020). A previous study showed that a considerable portion of the coal mine dust collected in different mine sites is in the size of submicron (Sarver et al. 2020).

The characteristics of selected publications in the systematic review are as below:

(1) There are consistent data related to the coal mines employee/production, RCMD disease, and exposure in the U.S. provided by MSHA, NIOSH, EIA, etc.
(2) All of the studies in the U.S. agreed more investigations are needed to find the contributing factors related to the recent resurgence of lung diseases.
(3) There has been significant progress in recent characterization studies, including characterization of submicron RCMD particles.
(4) Most studies focused on the prevalence of CWP cases in the Appalachia region (Kentucky, West Virginia, Pennsylvania, and Virginia) since most of the cases were observed in this region.
(5) It has been confirmed that RCMD characterization is different between mines.
(6) Recent studies have focused on the investigation of contributing mining factors in the prevalence of mine diseases (e.g., the effect of mine size in the prevalence of CWP among Appalachia coal mines).
(7) More than 40% of articles in the database were related to RCMD health-disease, and exposure-regulation. Therefore, there has been a tremendous effort to address this issue and study the the efficacy of the current RCMD regulations and monitoring approaches.

Table 2 Summary of selected papers for systematic review analysis

Author (Year)	Data source, period	Number of data	Geographic location	Exposure	Type of analysis	Results and recommendations
Morgan et al. (1973)	A large field study conducted by United States Public Health Service (USPHS), and United States Bureau of Mines in 1969	9076 coal miners	Pennsylvania (8 mines), West Virginia (9 mines), Kentucky (3 mines), Virginia (2 mines), Alabama (2 mines), Illinois (2 mines), Utah (2 mines), Ohio (1 mine), Indiana (1 mine), Colorado (1 mine)	Coal rank, age, mining tenure, CWP prevalence, geographic location	Statistical analysis	Physical and chemical composition of the coal dust could be responsible for the prevalence of lung diseases in different geographic regions. Coal rank is another factor that could play a significant role in the prevalence of lung diseases.
Laney et al. (2010)	Chest x-rays data from Coal Workers' X-ray Surveillance Program (CWXSP) during 1980–2008	90,973 coal miners	U.S. underground coal mines	Age, sex and employment history, geographic location	Log binomial regression	The prevalence of CWP during the last decade indicates an excessive exposure of silica dust among U.S. coal miners. The ratios of radiographs showing r-type opacity were increased in the 1990s among coal workers from Kentucky, Virginia, and West Virginia (prevalence ratio: 2.5).
Gamble et al. (2011)	Published reports during 1970–2010	8 reports were selected for Critique	U.S. coal mines (5 studies) British coal mines (3 studies)	Geographic location, dust exposure, age, mine size, coal rank, miner tenure	Review	The rank of coal in the U.S. eastern mines is higher than in western mines. Therefore, there are less cases of CWP in the western mines. Reports indicated a modest change in CWP prevalence at the end 1990s, although the CMD exposure had not been raised concomitantly.
Vallyathan et al. (2011)	National Coal Workers' Autopsy Study from 1971 through 1996	6103 coal miners	U.S. underground coal mines	Mining tenure, geographic location, age at death, ever smoker	Statistical analysis	For the coal workers who worked mostly in post-1969, the level of prevalence decreased. The research indicated a desirable effect on the incidence of CWP in U.S. coal miners for the first 25 years of dust standards developed under the Act of 1969.
Suarthana et al. (2012)	CWXSP during 2005–2009	12,804 coal miners	U.S. underground coal mines	Dust exposure, tenure, miner age, and coal rank	X^2 Testing	The prevalence of CWP found in central Appalachia was significantly above expected levels. Mining factors such as the size of mines and low seam mining are possibly contributing factors linked with increased exposure to silica.

Table 2 (continued)

Author (Year)	Data source, period	Number of data	Geographic location	Exposure	Type of analysis	Results and recommendations
Jenkins et al. (2013)	98 articles	34 articles were regarded as suitable for data extraction	USA(11) England(3) Netherlands(3) Germany(3) Great Britain (2) Japan (2) Spain (2) France (2) Australia (1) China (1) Czech public (1) Scotland (1) Belgium (1) Wales (1)	Year, country, study design, study period and study population, number of lung cancer, dust exposure	Systematic review	Risk assessment for 20 cancer site groups was documented, but their findings and frequency were substantially different. The risk assessments of incidence and mortality included: 12 sites were negative, one site positive, and seven sites discordant. Data are too meager to draw conclusive conclusions on population cancer risk. Further research on population exposure and risk is required because of the lack of evidence on population exposure and risk, the wide variety of coal mining operations, and the role of coal as a significant energy source in the U.S.
Graber et al. (2014)	MSHA compliance data from 1982–2002	9033 coal miners	31 U.S. underground mines (eastern Pennsylvania, eastern Appalachia, western Appalachia, Midwest, and West)	Smoking, age, geographic region (coal rank), race, calendar year, quartz	Cox proportional hazard analysis	According to this research, the results confirm previous research, which indicates that, even in the absence of smoking, exposure to RCMD and silica dust contributes to increased mortality from malignant and non-malignant respiratory diseases. There was a moderate correlation between RCMD and silica exposure among underground coal mines (Coefficient = 0.29, $p < 0.01$).
Blackley et al. (2014)	The Enhanced CWHSP (ECWHSP) during 2005–2012	4491 coal miners	Underground coal mines in Kentucky, Virginia, and West Virginia	Coal workers' demographics, underground mining tenure, smoking, body mass index (BMI)	Log-binomial regression	Around 25% of coal workers who participated in the program had CWP, abnormal lung function, or both. Coal miners in the small mines are at higher risk of abnormal spirometry (18.5% vs. 13.8%, $p < 0.01$), CWP (10.8% vs. 5.2%, $p < 0.01$) and progressive massive fibrosis (2.4% vs. 1.1%, $p < 0.01$) than larger mines.
Beer et al. (2017)	2665 articles	8 articles were regarded as suitable for data extraction	USA (1 study) U.K. (7 studies) Germany (1 study)	Year, country, study design, study period and study population, number of exposed and controls, age and age range, exposure levels and duration	Systematic review	The level of evidence is limited for causal links between exposure to pure coal powder and ILD. Further analysis of the data related to miners exposed to non-or very small content of mineral particles is required.

Table 2 (continued)

Author (Year)	Data source, period	Number of data	Geographic location	Exposure	Type of analysis	Results and recommendations
Graber et al. (2017)	Black lung benefits program (BLBP) data (2001 to 2013)	24,686 claimants	U.S. coal mines	Age, coal mining tenure, filing date, and the regional office	Ordinal logistic regression models	8.5% of the applicant had advanced CWP/ PMD, and the prevalence was higher for younger (< 57 years;10.8%) than older (> 70 years; 8.4%) coal workers. It would be more beneficial if the surveillance data, including smoking history, gender and race, are used for surveillance and analysis, were electronically recorded and standardized.
National Academies of Sciences, Engineering, and Medicine (NAS 2018)	Available MSHA/ NIOSH/CDC data for monitoring, sampling, and surveillance program	–	U.S. underground coal mines	Monitoring and sampling approaches	Review	The analysis of possible explanations for the recent considerable CWP increase seems very complicated.A systematic review of occupational exposure to RCMD should be conducted by health and safety occupational organizations. There has been a need to evaluate exposure for coal workers not wearing Continuous Personal Dust Monitor (CPDM) to ensure that detecting approach and mitigating high exposures for defined occupations reliably results in the minimizing of high exposures for all workers.It is necessary to investigate whether the CPDM readings represent the actual exposure dose to which a coal miner is exposed.
Almberg et al. (2018)	Federal Black Lung Program benefits, 1970–2016	4679 claimants	U.S. underground coal mines	Geographic location,	Logistic and linear regression models	Since 1978, the proportion of federal black lung claimants with PMF has risen with a dramatically increased prevalence rate (0.26% annual percent change) since 1996. There was a resurgence in PMF in the U.S, especially in the central Appalachian coal mines. The resurgence of this disease suggests that dust-prevention needs to be improved among coal mines.

Table 2 (continued)

Author (Year)	Data source, period	Number of data	Geographic location	Exposure	Type of analysis	Results and recommendations
Hall et al. (2019)	CWHSP data (1974–2018)	Underground coal miners participating in the CWHSP	U.S. underground coal mines	Prevalence of CWP	Literature review	Thin coal seams or higher volumes of overburden may contribute to a higher level of coal worker exposure to silica than in the past. The increased emphasis on scientific and the media has caused significant changes in pneumoconiosis prevention initiatives for coal mining companies and mitigated their negative health consequences, including increased federally funded financing of black lung clinics by 40%.
Doney et al. (2019a)	MSHA inspector-collected respirable dust and quartz (crystalline silica) underground coal mine data, 1982–2017	681,497 RCMD samples, 210,944 silica samples	U.S. underground coal mines	Respirable dust exposure concentration, year, occupations, geographical areas	Statistical analysis like geometric mean	The geometric mean of RCMD concentration in central Appalachia was lower than other coal mines of the U.S. However, the geometric mean of respirable quartz in that area was higher than the rest of the United States. 5.5% of RCMD samples exceeded the PEL of 2.0 mg/m^3. 2.0% of silica samples exceeded the PEL.
Doney et al. (2019b)	MSHA inspector-collected respirable dust and quartz (crystalline silica) surface coal mine data, 1982–2017	288,705 RCMD samples, 54,040 silica samples	U.S. surface coal mines	Respirable dust exposure concentration, year, occupations, geographical areas	Statistical analysis like geometric mean	The occupational geometric means for respiratory coal and quartz dust in active mining areas among drillers were the highest, especially in central Appalachia. 1.6% of RCMD samples exceeded the PEL of 2.0 mg/m^3. 15.3% of silica samples exceeded the PEL.
Sarver et al. (2019)	Respirable dust samples collected from mines during 2014–2015	76 (sample sets)	Central Appalachia (6 mines) Northern Appalachia (2 mines)	Geographic location, elemental, underground location, RCMD sources	Composition, mineralogy distributions, particle size, bioaccessibility	Four significant sources of RCMD were found to be coal seam, rock strata, rock dusting, and diesel engine emissions. Observations indicated that most dust particles exhausted from diesel equipment are in the submicron size range. RCMD characterization is different from one mine to another mine.

Table 2 (continued)

Author (Year)	Data source, period	Number of data	Geographic location	Exposure	Type of analysis	Results and recommendations
Leonard et al. (2020)	Coal Workers' Health Surveillance Program, 1974–2015	60,000 coal miners	U.S. coal mines	Mine type, dust composition, duration and intensity of exposure, the thickness of coal seams, the presence of bioavailable iron and operation size	Review paper	Due to poor compliance with dust regulation, small mines, thin coal seams, and dust composition changes, the incidence of the CWP tends to increase in the U.S. A few possible explanations for the recent resurgence in CWP might be poor compliance and inadequate RCMD regulation, increased thinner seam mines, participation bias (which has been rejected), inadequate health screening involvement of miners, and poor implementation of dust controls.
Hall et al. (2020)	Coal Workers' Health Surveillance Program (CWHSP) data (2014–2019)	11,255 coal mines	U.S. surface coal mines	Demographic information, mining tenure and occupation, and radiographic classifications	log-binomial regression	Among coal miners in the U.S. surface mines, 1.6% had CWP, in which the number of cases in the Central Appalachia was more significant than the rest of mines in the U.S. The rate of lung diseases for drillers or blasters was higher than miners with other jobs in the surface mines. The prevalence of CWP among surface coal miners supports their inclusion in a systemic surveillance program of respiratory health.

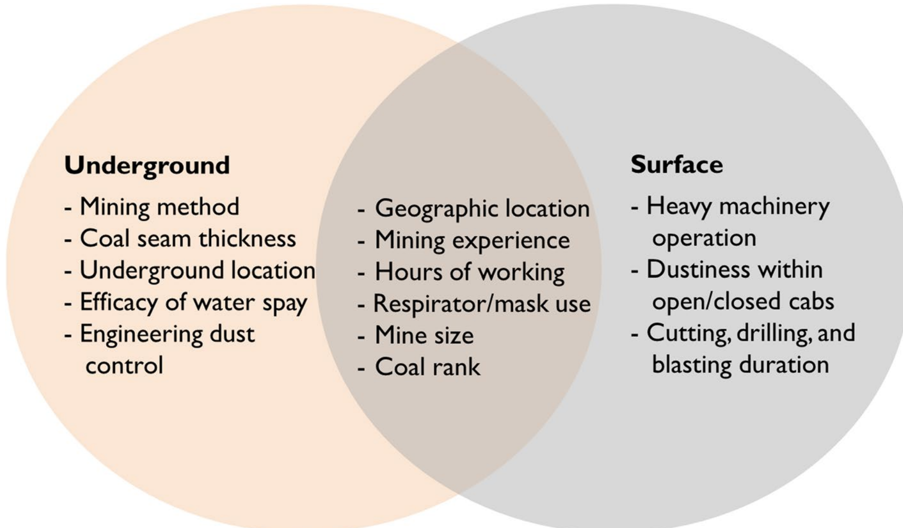

Fig. 4 Key risk factors contributing to the respiratory health of the underground and surface coal miners (Go et al. 2016; Perret et al. 2017)

(8) The total number of publications related to RCMD published recently has been increased; therefore, the topic of RCMD is of concern for many researchers in the U.S.

A closer look at the previous studies reveals several deficiencies. First, the effects of all the contributing mining parameters (i.e., mining operation type, mine size, coal rank, coal seam thickness, geographic location, etc.) on the prevalence of CWP have not been investigated in a multivariable model (Shekarian et al. 2021a). Second, there has been no research to compare the prevalence of lung diseases in surface and underground mines. Third, the confidence levels and p-values of analysis in a few of the selected studies are missing, and it is not clear whether the identified relationships in those studies were statistically significant. Therefore, with the limited data available in previous studies, it is difficult to conclude to what extent those studied factors may have contributed to the recent resurgence of CWP. Fourth, the worker's health history and any previous illnesses/disabilities have not been systematically collected. Fifth, a major flow in the previous studies was the assumption that miners were exposed to a constant level of dust exposure at the same job during the entire employment tenure (Vallyathan et al. 2011; Graber et al. 2014; Shekarian et al. 2021b). Finally, the primary focus of the selected publications was focused on underground coal mines in the hot spot areas (i.e., West Virginia, Virginia, Pennsylvania, and Kentucky), and the data from other regions and mining methods were excluded.

In addition to the aforementioned drawbacks in previous studies, information on key parameters and their relationships with the prevalence of CWP are missing. Information related to several factors such as mining technology changes, advancement in cutting machineries, and disease latency time is insufficient. There is also limited data on the lung deposition of submicron RCMD particles since most of the data collected in previous studies were in supramicron range of 3–10 microns (NAS 2018; Sarver et al. 2019). There is also a gap in knowledge to investigate which and how the compositions of RCMD may cause high rates of CWP and silicosis among coal miners.

There have been tremendous efforts to identify the contributing factors in developing lung diseases among coal miners. The analysis of possible explanations for the recent increase in CWP seems very complicated. Changes in mining practices, technology advancement, thin coal seam mining, rock dusting, the efficacy of water spay and mitigation techniques, engineering dust control, hours of working, and new cutting machinery may each contribute to the occurrence of new CWP cases in the US (See Fig. 4) (Volkwein et al. 2006; Colinet et al. 2010; Brown et al. 2013; Scaggs 2016; NAS 2018; Thakur 2019; Shekarian et al. 2021a). Further investigations are required to identify the root causes of the lung diseases resurgence and the contributing factors (Brown et al. 2013; NAS 2018; Johann-Essex et al. 2017; Sarver et al. 2019).

4 Conclusions

In the United States, the manifestation of black lung disease was in the 1960s when 30% of workers who had more than 25 years of tenure in underground coal mines reported developing CWP disease. There has been a significant effort since

1969 to address this issue by reducing the PEL of respirable coal and silica dust. This study aimed to investigate various contributing factors in the recent resurgence of CWP among coal miners in U.S coal mines by conducting a systematic review. Hence, available statistics and data on coal mine dust lung disease were collected from the literature to identify the critical medical, engineering, and mining factors contributing to the resurgence of CWP among coal miners in the United States. Of the 401 publications in the database, 148 studies were excluded in the title and abstract screening, 208 studies in the full-text assessment. Finally, a total number of 18 papers were selected by snowball research and full-text assessment of publications for the data extraction. The systematic review results showed that there are various contributing factors, including mine type, geographic location, technological development, level of automation, thin coal seam mining, application of rock dusting, coal rank, and changes in mining practices that can contribute to the increase of lung diseases. However, there has been no comprehensive systematic review to determine all the contributing factors associated with the recent resurgence of lung disease among U.S. coal miners. Furthermore, there are various limitations to those studies. For instance, the gender, race, mean, and median of miners' age were not provided in many of those studies. Also, the vast majority of research studies focus on RCMD occupational exposure in underground mines. However, it is worth mentioning that respiratory lung disease is also a prevalent health issue among surface coal miners.

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Author contributions YS: Conceptualization, Methodology, Formal analysis, Investigation, Writing – Review & Editing, Visualization. ER: Conceptualization, Methodology, Formal analysis, Investigation, Writing – Review & Editing, Visualization. MR: Supervision, Project administration, Funding acquisition, conceptualization, Investigation, Writing – Review & Editing, Guarantor of the paper. PR: Supervision, Project administration, Funding acquisition, conceptualization, Methodology, Formal analysis, Investigation, Resources, Data Curation, Writing – Review & Editing, Guarantor of the paper. All authors read and approved the final manuscript.

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Declarations

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