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EXPOSURE LIMIT VALUE TO RESPIRABLE CRYSTALLINE SILICA – A SYSTEMATIC REVIEW

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Abstract
Background: Silicosis is a worldwide occupational fibrotic respiratory disease caused by inhaling respirable crystalline silica. There is a lack of knowledge about the limiting value of silica exposure in work labor or environment and compliance with this limit defined by national legislation. **Objective:** This systematic review describes how the limit value of silica dust exposure varies across the world and if people's exposure to silica dust exceeds the permissible level. **Methods:** The review considered peer-reviewed research articles published in English between 2018 and 2023. The study population included people who were exposed to silica dust. Twenty-one articles were eligible from Scopus, PubMed, and ISI Web of Knowledge databases. **Results:** The occupational and non-occupational populations were exposed to silica levels that exceeded the permissible value. Recognizing the non-accomplished standard limits is an opportunity to evaluate the production methods of industries, personal operating procedures, and guidelines of prevention rules. It is an opportunity to define environmental exposure limits for silica, rules for individual and collective protection, and screening strategies at regular occupational medicine consultations. **Conclusion:** The systematic review highlights the need for further research into guidelines for defining safe exposure silica dust limits and applying prevention measures.

Keywords: silica dust, silicosis, exposure limit value, occupational health.

Introduction

Silicosis, a fibrotic respiratory disease, is caused by inhaling respirable crystalline silica, the earth's most abundant mineral (Leung *et al*., 2012). Its toxicity arises from oxygen radicals that damage pulmonary cells, particularly alveolar macrophages, which release cytotoxic oxidants and inflammatory cytokines, driving fibrosis and inflammation (Rimal *et al*., 2005). The global incidence of silicosis continues to rise due to increasing silica exposure in high-demand occupations and insufficient protective measures. In 2017, the Global Burden of Disease study reported 23,695 new silicosis cases, accounting for 39% of all pneumoconiosis cases(Hoy *et al*., 2022).

The diagnosis of silicosis depends on a clear occupational history of substantial silica exposure and compatible radiological features. Chest radiography is the primary method of diagnosis with small round opacities distributed with upper-zone predominance. The radiologic evaluation is based on the International Labor Organization (ILO) classification of pneumoconiosis radiographs, and the diagnosis can be supported by a profusion score ≥ 1/0 per ILO classification (PNEUMOCONIOSES, 2002). Other possible diseases need to be ruled out to conclude the diagnosis (Fernández Álvarez *et al*., 2015).

The widespread usage of crystalline silica in the industry has long been recognized as a serious occupational hazard. Occupational exposure occurs in a variety of industries, including architecture and construction, as well as mining, craftsmanship (stonecutting), cutting-edge technology (dental prosthesis), farming, trendy artificial stones (kitchen benchtop made of faux stone), and apparel (stone-washed jeans) (Hoy *et al*., 2022).

In 1995, the World Health Organization began a campaign to eliminate silicosis worldwide by 2030, but silicosis remains a significant health issue internationally (Hoy & Chambers, 2020). Several foreign studies have indicated silicosis emerging in new settings, including environmental exposure. Environmental emissions of silica can arise from natural, industrial, and farming activities. In general, it is more likely that occupational crystalline silica exposures have been studied. The data available on non-occupational exposures to other forms of silica are minimal (EPA, 1996). The innovative "environmental silicosis" concept remains understudied and can change the silicosis diagnosis paradigm. Non-occupational exposures to respirable crystalline silica are also possible, particularly in communities near silica-dust-generating sources. Non-occupational exposure can occur naturally due to desert dust and sandstorms in mountainous areas or dust emitted from industries that can affect nearby people through inhalation (Bhagia, 2012).

Inhaling respirable crystalline silica can have harmful effects on a person's health in addition to silicosis, such as lung cancer, chronic obstructive pulmonary disease, and pulmonary tuberculosis (Keramydas *et al*., 2020). Targeted prevention requires a deeper comprehension of the influencing factors, including crystalline silica emissions and people's silica dust exposure (Xu *et al*., 2023). There is a lack of knowledge regarding silica dust emissions in several industrial sectors and about the exposure limit value (ELV) and compliance of this limit defined by national legislation (Ehrlich *et al*., 2021).

Putting it all together, how does the silica dust ELV vary across the world? Do people's exposure to silica dust exceed the permissible level? This systematic review aimed to find evidence in the literature on the worldwide limit value for exposure to silica dust and investigate the legislation compliance about silica powder exposure in the workplace and environment.

Materials and methods

Search strategy, inclusion criteria and data extraction

This systematic review was conducted following the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Page *et al*., 2021). The search was performed by introducing the selected keywords into the search fields in Scopus, PubMed, and Web of Science. The authors considered that these three multidisciplinary databases were enough to cover the possible spectrum for the research. Additionally, the fields had to be adapted to provide comparable data and allow the reproducibility of work. The Boolean expression summarizing the combinations is ("dust" OR "dusting" OR "particulate" OR "powder") AND ("exposure limit" OR "emission limit" OR "limit value") AND ("crystalline silica"). This expression was broad enough not to exclude critical information initially. The research was carried out in June 2023.

The exclusion criteria were (1) Date—only papers published between 2018 and 2023 were included; (2) Type of document— only research articles were included; (3) Source type— only peer-reviewed journals were considered; and (4) Language— only articles written in English were included. All the records were managed with Endnote software, where the duplicate files were removed. To be included in the research, the focus of the remaining articles had to be on (1) presenting the acceptable silica exposure standard according to the different established committees on Occupational ELV; (2) accessing the measurements of personal exposure to respirable particles of respirable crystalline silica at any context, occupational and non-occupational, and (3) discussing the fulfill of the ELV of silica exposure. New potentially relevant reports were identified through the eligible papers' forward and backward citation tracking.

The following information was extracted: (1) study characteristics: first author name, publication year, country; (2) type of study; (3) study objective; (4) source of exposure (such as occupational setting or non-occupational exposure); (4) information about the outcome of interest (ELV established and compliance with the standard rules) (Table 1).

Quality assessment

To summarize the risk-of-bias assessments, a traffic light plot was created using the Robvis tool (McGuinness & Higgins, 2021) (Table 2).

Results and Discussion

Research Results

Over 288 articles were identified in the initial stages of the research, from which 195 were removed according to the exclusion criteria. The references were imported to the Endnote reference manager, and 65 duplicate references were identified and excluded. Of the remaining, five articles were excluded by reading the title and abstract and assessed for relevance to the topic. 23 articles were then assessed for eligibility. Four articles were excluded because they were out of the topic. One new relevant full-text report was identified through forward and backward citation tracking of the articles included in the systematic review. Finally, 20 studies were included. The summary of the research is found in Figure 1.

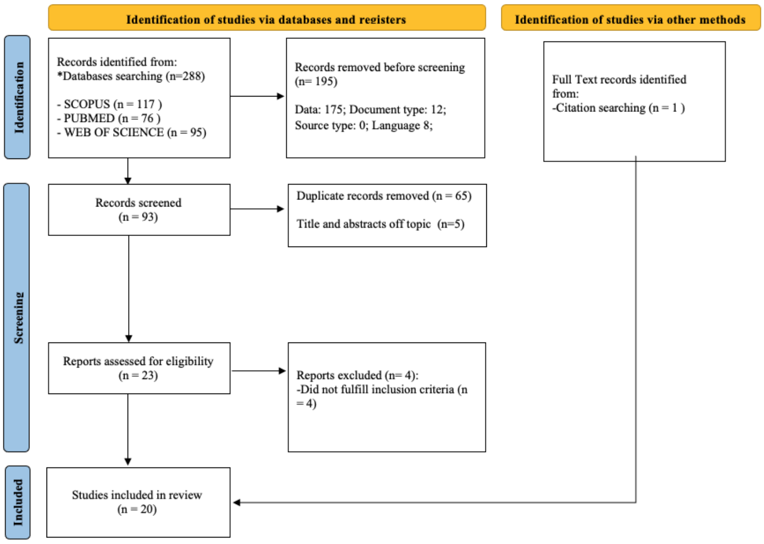

***Figure 1**. Flow diagram of literature search adapted from PRISMA 2020 (Page et al., 2021)*

Studies' Analysis

The final analysis included 20 cross-sectional studies assessing workplace or environmental exposure to respirable crystalline silica, summarized in Table 1. Key factors analyzed were study year, location, exposure context, and compliance with silica exposure limits. Among the studies, 15 focused on non-mining activities (e.g., cement, construction), while six targeted mining. Only one study evaluated non-occupational exposure (Andraos *et al*., 2018).

The studies spanned five continents, primarily Asia and Europe, with varying national silica ELV. For instance, OSHA and NIOSH in the U.S. recommend an occupational ELV of 0.05 mg/m³ over an 8-hour shift, similar to Safe Work Australia and Egyptian standards (Australia, 2020; Mohamed *et al*., 2018; OSHA, 2019).

However, exposures in many studies exceeded these thresholds. In contrast, some studies reported compliance, such as Rumchev *et al*., though adverse health effects were still noted (Rumchev *et al*., 2022). The ACGIH recommends a stricter limit of 0.025 mg/m³, adopted in studies from Italy and Vietnam, while EU limits vary, with Greece and Great Britain applying a 0.1 mg/m³ standard ((ACGIH), 2012; Baldwin *et al*., 2019; Keramydas *et al*., 2020).

Silica ELV also differ across regions. For example, Switzerland and India set limits of 0.15 mg/m³, while United States of America (USA) standard is 0.05 mg/m³ (Table 1). Despite compliance in some cases, health risks, including silicosis, were documented at these levels (Dhatrak & Nandi, 2020).

California's OEHHA proposes an ambient limit of 3 µg/m³, which Kim *et al*. and Andraos *et al*. highlighted in sanitation and community exposure studies, respectively, underscoring the need for stricter non-occupational assessments (Andraos *et al*., 2018; Kim *et al*., 2021).

These findings reveal significant discrepancies in silica exposure standards and compliance globally. The literature suggests that even exposure below permissible ELV poses risks, emphasizing the need for unified regulations and further research into non-occupational exposures.

This investigation revealed that silica levels around facilities often exceed international limits, posing potential health risks, including cancer (Andraos *et al*., 2018). Non-occupational exposure to silica is a growing concern, with evidence of exposure through natural sources like desert dust, sandstorms, and industrial emissions affecting nearby populations (Andraos *et al*., 2018; Bhagia, 2012). Comprehensive studies on non-occupational silica exposure and its health implications remain scarce.

Table 1. *Summary of selected articles*

References	Date	Region	Design	Exposure	Exposure limit value	Limit value overtake
(Omidianidost *et al*., 2019)	2019	Iran	Cross-sectional study	Occupational/Cement plant	0.025 mg/m^3	Yes
(Bello *et al*., 2019)	2019	USA	Cross-sectional study	Occupational/Construction	0.05 mg/m^3	Yes
(Keramydas *et al*., 2020)	2020	Greece	Cross-sectional study	Occupational/Construction	0.10 mg/m^3	No
(Dhatrak & Nandi, 2020)	2020	India	Cross-sectional study	Occupational/Mining	0.15 mg/m^3	Yes
(Cothern *et al*., 2023)	2023	USA	Cross-sectional study	Occupational/Construction	0.05 mg/m^3	Yes
(Park *et al*., 2020)	2020	South Korea	Cross-sectional study	Occupational/Construction	0.05 mg/m^3	Yes
(Rumchev *et al*., 2022)	2022	Australia	Cross-sectional study	Occupational/Mining	0.05 mg/m^3	No
(Mensah *et al*., 2020)	2020	Gana	Cross-sectional study	Occupational/Mining	0.05 mg/m^3	Yes
(Koller *et al*., 2018)	2018	Switzerland	Cross-sectional study	Occupational/Different sectors	0.15 mg/m^3	Yes
(Kim *et al*., 2021)	2021	South Korea	Cross-sectional study	Occupational/Sanitation workers	3 $\mu g/m^3$	Yes
(Omidianidost *et al*., 2019)	2019	Iran	Cross-sectional study	Occupational/Cement plant	0.025 mg/m^3	Yes
(Bello *et al*., 2019)	2019	USA	Cross-sectional study	Occupational/Construction	0.05 mg/m^3	Yes
(Keramydas *et al*., 2020)	2020	Greece	Cross-sectional study	Occupational/Construction	0.10 mg/m^3	No
(Dhatrak & Nandi, 2020)	2020	India	Cross-sectional study	Occupational/Mining	0.15 mg/m^3	Yes
(Cothern *et al*., 2023)	2023	USA	Cross-sectional study	Occupational/Construction	0.05 mg/m^3	Yes
(Park *et al*., 2020)	2020	South Korea	Cross-sectional study	Occupational/Construction	0.05 mg/m^3	Yes

References	Date	Region	Design	Exposure	Exposure limit value	Limit value overtake
(Rumchev *et al.*, 2022)	2022	Australia	Cross-sectional study	Occupational/Mining	0.05 mg/m^3	No
(Mensah *et al.*, 2020)	2020	Gana	Cross-sectional study	Occupational/Mining	0.05 mg/m^3	Yes
(Koller *et al.*, 2018)	2018	Switzerland	Cross-sectional study	Occupational/Different sectors	0.15 mg/m^3	Yes
(Kim *et al.*, 2021)	2021	South Korea	Cross-sectional study	Occupational/Sanitation workers	3 μg/m^3	Yes
(Blagrove-Hall *et al.*, 2021)	2021	Canada	Cross-sectional study	Occupational/Mining	0.025 mg/m^3	Yes
(Mastrantonio *et al.*, 2021)	2019	Italy	Cross-sectional study	Occupational/Construction	0.025 mg/m^3	No
(Mohamed *et al.*, 2018)	2021	Egypt	Cross-sectional study	Occupational/Different sectors	0.05 mg/m^3	Yes
(Misra *et al.*, 2023)	2023	USA	Cross-sectional study	Occupational/ Mining	0.05 mg/m^3	Yes
(Baldwin *et al.*, 2019)	2019	Great Britain	Cross-sectional study	Occupational/ Different sectors	0.10 mg/m^3	Yes
(Beaucham *et al.*, 2018)	2018	USA	Cross-sectional study	Occupational/ Different sectors	0.05 mg/m^3	Yes
(Boudigaard *et al.*, 2022)	2022	Denmark	Cross-sectional study	Occupational/ Different sectors	0.025 mg/m^3	Yes
(Thai *et al.*, 2021)	2021	Vietnam	Cross-sectional study	Occupational/ Cement plant	0.025 mg/m^3	Yes
(Prajapati *et al.*, 2021)	2021	India	Cross-sectional study	Occupational/ Mining	0.15 mg/m^3	No
(Andraos *et al.*, 2018)	2018	South Africa	Cross-sectional study	Non-occupational	3 μg/m^3	Yes

This systematic review synthesizes global silica exposure limits, highlighting inconsistencies across countries and within the same nation, where different guidelines are applied without clear criteria (Ehrlich *et al*., 2021). Although our findings must be considered preliminary because of the broadening of the temporal criterion and possibly of the databases are needed to meet the objective of the final study, our findings have several important public health implications. Analyzing the global data, the ELV are different, and within the same country different guidelines are used without specific criteria. At the same time, workplace silica concentrations frequently exceed occupational ELV, and even low exposures can cause disease. Effective measures, including air monitoring, improved technologies, and collaboration on regulatory frameworks, are essential to mitigate exposure risks (Cothern *et al*., 2023; Zhao *et al*., 2019).

The heterogeneity of the studies is high (Table 2), reflecting variability in legislation, source-specific data, and sampling methods, which complicate comparisons. The quality assessment highlights a lack of standardization in the definition of "environmental exposure," as applied to different work settings with varying conditions.

Conclusions

Silicosis is a progressive and irreversible, disabling interstitial lung disease caused by inhalation of respirable crystalline silica. The systematic review highlights the importance of guidelines review and controlling the compliance of standard limits of silica dust exposure. Only one study was not conducted in an occupational context and the search included reports from different countries and continents.

Returning to the issue raised in the introduction about the variability of the limit value of silica dust exposure and if these limits are accomplished, the answer is worrying. The data collection shows that although permissible exposure limits are established by regulatory agencies, this does not mean that all workplaces meet these standards. Furthermore, the permissible silica exposure limits are not protecting the health of exposed people. It is important to remember that "safe" levels may not necessarily correspond to the exposure limits allowed. Even low amounts, according to some studies reviewed, can have long-term adverse effects on one's health. As such, every effort should be made to limit exposure.

Targeted prevention requires a deeper comprehension of the influencing factors and social or country context. These results opened our eyes to what needs to be improved. All companies need to be systematically informed about occupational health risks, field inspections must be consistent.

***Table 2**. Risk of Bias Assessment of observational studies (ROBINS E-tool)*

Study	Risk of bias domains: D1	D2	D3	D4	D5	D6	D7	Overall
(Omidianidost, Gharavandi et al. 2019)	-	X	X	-	+	-	X	-
(Bello, Mugford et al. 2019)	+	-	+	+	?	+	+	+
(Ehrlich, Noll et al. 2021)	+	-	+	?	+	+	+	+
(Keramydas, Bakakos et al. 2020)	+	+	+	+	+	+	+	+
(Dhatrak and Nandi 2020)	+	+	+	?	?	+	+	+
(Cothern, Brazile et al. 2023)	-	+	+	?	-	-	+	-
(Park, Hwang et al. 2020)	+	-	+	+	+	+	+	+
(Rumchev, Hoang et al. 2022)	+	+	+	+	?	+	+	+
(Mensah, Mensah-Darkwa et al. 2020)	-	X	-	?	-	-	-	-
(Koller, Scholz et al. 2018)	-	+	-	-	-	-	-	-
(Kim, Kim et al. 2021)	+	+	-	+	+	+	-	+
(Blagrove-Hall, Berriault et al. 2021)	+	+	+	?	+	+	+	+
(Mastrantonio, Civisca et al. 2021)	+	+	+	?	?	+	+	+
(Mohamed, El-Ansary et al. 2018)	+	+	+	+	+	+	+	+
(Misra, Sussell et al. 2023)	-	X	X	-	-	-	X	-
(Baldwin, Yates et al. 2019)	+	+	+	+	+	+	+	+
(Beaucham, King et al. 2018)	+	+	+	?	?	+	+	+
(Boudigaard, Hansen et al. 2022)	-	-	-	-	-	-	-	-
(Thai, Bernatik et al. 2021)	+	+	-	+	?	+	-	+
(Prajapati, Mishra et al. 2021)	+	+	+	?	+	+	+	+
(Andraos, Utembe et al. 2018)	+	+	+	+	?	+	+	+

Domains:
D1: Bias due to confounding.
D2: Bias arising from measurement of the exposure.
D3: Bias in selection of participants into the study (or into the analysis).
D4: Bias due to post-exposure interventions.
D5: Bias due to missing data.
D6: Bias arising from measurement of the outcome.
D7: Bias in selection of the reported result.

Judgement
X High
- Some concerns
+ Low
? No information

and regular, and health surveillance of all exposed workers must be implemented regularly. To do this, efforts must be taken to measure worker exposure to silica and ensure that it is below the permissible exposure level. Employers must take preventive action to decrease exposure if workers are exposed to silica. This can entail implementing dust-control measures (such as ventilation or water), regulating employees' time in dusty environments, or supplying respirators. Health education and the implementation of efficacy and safety of personal and environmental protection equipment must be provided for a better future.

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