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The relationship between elevated blood metal levels and pneumoconiosis profusion scores and opacity size: a study on foundry workers

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ABSTRACT

Aims: This study aims to describe the demographic, clinical, and radiological characteristics of foundry workers diagnosed with pneumoconiosis and to investigate the association between blood metal levels and disease severity, with particular emphasis on radiological grading based on the International Labour Organization (ILO) classification, including profusion scores and small opacity types.

Methods: A total of 45 foundry workers with radiologically confirmed pneumoconiosis were included. Data on age, smoking history, pulmonary function tests, occupational duration, working units, and blood metal concentrations were collected. Radiological assessment was conducted using the ILO classification. Workers were categorized into two groups based on whole blood metal concentrations (normal vs. elevated). Additionally, radiological severity was compared across work units. Comparative and correlation analyses were performed.

Results: The cohort consisted predominantly of males (97.8%) with a mean age of 50.1±7.8 years and a mean work duration of 18.3±8.9 years. Profusion scores were categorized as 1 in 55.6% and >1 in 44.4% of the workers. The most common opacity pattern was small, rounded type p (75.6%). A statistically significant inverse correlation was observed between blood metal levels and profusion scores ($r=-0.348$, $p=0.019$), while profusion and opacity size were positively correlated ($r=0.335$, $p=0.025$). Neither work duration nor smoking history showed a significant association with radiologic severity. Notably, workers in grinding and sandblasting units exhibited more advanced radiological findings despite having blood metal levels within the normal range.

Conclusion: The severity of pneumoconiosis may not directly correlate with measured blood metal levels but appears to be influenced by exposure characteristics, specific work units, and possibly the effectiveness of protective measures. These findings underscore the importance of comprehensive occupational risk assessments beyond conventional blood metal biomonitoring.

Keywords: Pneumoconiosis, foundry workers, ILO radiologic classification, blood metal levels

INTRODUCTION

Pneumoconiosis remains a significant occupational health concern worldwide, particularly in industries with exposure to mineral and metal dusts such as foundries and welding environments. Although traditionally associated with mining or silica-rich industries, pneumoconiosis related to welding fumes and metal particles is increasingly recognized, especially in developing countries where industrial hygiene measures may be inconsistent.[1] Welder's siderosis, once considered benign and reversible, is now understood to be potentially progressive and capable of causing clinically significant respiratory impairment in certain cases.[2,3]

The International Labour Organization (ILO) classification provides a standardized radiographic method for identifying and grading pneumoconiosis severity, focusing on profusion and opacity characteristics.[4] Despite its widespread use, limited data exist on how these radiologic parameters correlate with specific occupational exposures, such as heavy metal fumes, particularly among foundry workers.

Furthermore, the relationship between whole blood metal levels and the clinical or radiologic severity of pneumoconiosis remains unclear. While higher exposure is intuitively expected to result in more severe radiologic findings, recent observations suggest that factors such as particle size, composition, individual susceptibility, and workplace protections may confound this relationship.[5,6]

Recent studies also emphasize the inadequacy of using only systemic biomarkers to estimate lung burden in workers exposed to complex dust environments.[7,8]

This study aimed to describe the clinical, functional, and radiologic characteristics of foundry workers diagnosed with pneumoconiosis and to evaluate whether those with elevated whole blood metal levels exhibited more severe radiologic findings compared to those with normal levels. This study also explored the influence of work unit and duration on disease severity.

METHODS

Ethics

This study has been approved by the Scientific Researches Ethics Committee of Eskişehir City Hospital (Date: 25.06.2025, Decision No: ESH/BAEK 2025/201). All procedures complied with the Declaration of Helsinki and relevant institutional ethical guidelines. Written informed consent was waived due to the retrospective nature of the study and the use of anonymized data.

Study Design and Participants

This cross-sectional descriptive study included 45 foundry workers diagnosed with pneumoconiosis between January 2021 and May 2025 at tertiary Eskişehir City Hospital occupational diseases clinic in Turkiye. All cases met radiologic diagnostic criteria for pneumoconiosis based on the ILO classification system.[4]

Data Collection

Data were extracted from hospital records and included demographic variables such as age and sex, as well as occupational details including the specific job unit and total duration of work in years. Smoking status was categorized as current smoker, ex-smoker, or never smoker, and pack-years were calculated accordingly. Pulmonary function test results, including forced vital capacity (FVC), forced expiratory volume in one second (FEV1), and the FEV1/FVC ratio, were recorded from spirometry assessments. Radiological evaluations were performed according to the ILO classification system, documenting profusion scores, opacity type and size, and the presence of large opacities.

Definition of Metal Exposure Groups Based on Whole Blood Metal Levels

Participants were classified into two groups according to their whole blood metal concentrations, measured by atomic absorption spectroscopy and compared to established reference values:

Normal blood metal level group: Workers whose blood metal levels were within the normal reference range.

Elevated blood metal level group: Workers with blood metal concentrations exceeding the upper limits of the normal reference range.

Definition of metal exposure: The classification of metal exposure was based on occupational hygiene assessments and previous institutional observations regarding the expected levels of airborne metal dust and fumes within different foundry work units. This classification relies solely on the work unit and does not incorporate any biological measurements.

Low exposure group: Workers assigned to units such as grinding, sandblasting, and finishing, where high-temperature processes are generally absent, resulting in low levels of metal fume exposure. However, other particulate risks such as respirable dust (e.g., silica) may still be present.

High exposure group: Workers in units involving high-temperature and molten metal processes, including melting, casting, molding, and hot pressing. These operations are associated with intense generation of metal fumes and vapors, leading to higher exposure risk.

The purpose of this classification is to differentiate exposure profiles based on specific job functions within the foundry environment and to complement individual-level measurements with a work organization-based approach for a more comprehensive occupational risk assessment.

Inclusion and Exclusion Criteria

Inclusion criteria were: being a foundry worker with at least one year of occupational exposure, having a diagnosis of pneumoconiosis based on the ILO radiologic classification, and availability of both blood metal levels and chest radiographs. Exclusion criteria included the presence or history of other interstitial lung diseases (such as idiopathic pulmonary fibrosis), active or previous pulmonary tuberculosis, a diagnosis or suspicion of lung cancer, and missing data related to occupational exposure or radiologic evaluation.

Statistical Analysis

Descriptive statistics were calculated for all variables. Participants were grouped by blood metal level (normal vs. elevated). Group comparisons used chi-square tests for categorical variables and Mann–Whitney U tests for continuous variables (due to non-normal distribution). Spearman correlation assessed relationships between profusion scores, opacity size, work duration, and pack-years. A p-value <0.05 was considered statistically significant. Analyses were performed using SPSS version 20.0 (IBM Corp, Armonk, NY).

RESULTS

Demographic and Clinical Characteristics

Among the 45 workers (97.8% male), the mean age was 50.1±7.8 years, and the mean work duration was 18.3±8.9 years. Smoking prevalence was high (66.7% current smokers). Mean FVC was 88.0±14.0% predicted; mean FEV1 was 83.9±14.9% predicted (**Table 1a, 1b, 1c**).

Radiological Findings

According to the ILO classification, 55.6% of workers were in profusion category 1 and 44.4% in >1. The dominant opacity type was small rounded (type p, 75.6%), with 11.1% showing large opacities (primarily category A) (**Table 2**).

Table 1a. Demographic characteristics

Variable	n	Mean±SD or n (%)	Range or %
Age (years)	45	50.07±7.81	35-64
Sex	45	Male: 44 (97.8%)	Female: 1 (2.2%)
Smoking status	45	Current: 30 (66.7%)	Ex-smoker: 12 (26.7%), non-smoker: 3 (6.7%)
Pack-years category	45	<10: 5 (11.1%)	10–20: 14 (31.1%), >20: 23 (51.1%), non-smoker: 3 (6.7%)
Work duration (years)	45	18.29±8.93	2-40
Work units	45	Melting/casting/pot: 14 (31.1%)	Grinding: 10 (22.2%), shot blasting/ deburring/others: 21 (46.7%)

Table 1b. Pulmonary function tests

Variable	n	Mean±SD	Range
FVC (% predicted)	45	87.98±13.98	56-117
FEV1 (% predicted)	45	83.87±14.94	53-121
FEV1/FVC (%)	45	78.08±6.59	66-96

SD: Standard deviation, FVC: Forced vital capacity, FEV1: Forced expiratory volume in 1 second

Table 1c. Radiological characteristics

Variable	n	n (%) or category
ILO profusion category	45	Category 1: 25 (55.6%) Category >1: 20 (44.4%)
Opacity type	45	p: 34 (75.6%) q/r: 10 (22.2%) Irregular: 1 (2.2%)
Large opacity (A-C)	45	No: 40 (88.9%) A: 3 (6.7%) B: 1 (2.2%) C: 1 (2.2%)
Metal exposure level	45	Normal: 30 (66.7%) Elevated: 15 (33.3%)

ILO: International Labour Organization

Table 2. Comparison of clinical and radiologic parameters according to blood metal levels (normal vs. elevated)

Variable	Normal metal level (n=30)	Elevated metal level (n=15)	p-value
Age (years)	49.5±7.9	51.0±7.5	0.53
Male sex, n (%)	29 (96.7%)	15 (100%)	0.55
Current smoker, n (%)	20 (66.7%)	10 (66.7%)	1.00
Work duration (years)	19.5±9.3	16.2±7.2	0.18
FVC (% predicted)	85.7±14.1	92.0±12.3	0.11
FEV1 (% predicted)	82.0±15.4	87.8±13.1	0.20
FEV1/FVC (%)	77.6±6.7	79.0±6.1	0.41
ILO profusion category >1, n (%)	19 (63.3%)	1 (6.7%)	0.001
Large opacity present (A–C), n (%)	4 (13.3%)	1 (6.7%)	0.58

FVC: Forced vital capacity, FEV1: Forced expiratory volume in 1 second, ILO: International Labour Organization

Metal Level, Units and Radiological Severity

Elevated blood metal levels were identified in 33.3% of participants, while 66.7% had levels within normal range. An inverse correlation between blood metal levels and profusion score was observed (r=–0.348, p=0.019), indicating that workers with elevated metals tended to have less severe radiologic findings.

Profusion score was positively correlated with opacity size (r=0.335, p=0.025). No significant correlation was found between profusion and either smoking pack-years or work duration.

Interestingly, most workers in high-metal exposure units (e.g., smelting) had lower profusion categories despite higher systemic metal levels. Conversely, workers from low-metal exposure units (e.g., sandblasting) often presented with more severe radiographic findings (**Table 3a, 3b**).

Table 3a. Distribution of blood metal levels (normal vs. elevated) by work unit

Work unit	Normal metal level n (%)	Elevated metal level n (%)
Melting/casting/pot	6 (42.9%)	8 (57.1%)
Grinding	10 (100%)	0 (0%)
Shot blasting/deburring	14 (66.7%)	7 (33.3%)
Welding	1 (100%)	0 (0%)
Powder coating/paint shop	1 (50.0%)	1 (50.0%)
Assembly	2 (100%)	0 (0%)
Mold preparation	0 (0%)	1 (100%)

Table 3b. Distribution of ILO profusion categories by work unit

Work unit	Profusion category 1 n (%)	Profusion category >1 n (%)
Melting/casting/pot	10 (71.4%)	4 (28.6%)
Grinding	3 (30.0%)	7 (70.0%)
Shot blasting/deburring	12 (57.1%)	9 (42.9%)
Welding	1 (100%)	0 (0%)
Powder coating/paint shop	2 (100%)	0 (0%)
Assembly	1 (50.0%)	1 (50.0%)
Mold preparation	0 (0%)	1 (100%)

ILO: International Labour Organization

DISCUSSION

This study characterized the clinical and radiologic features of foundry workers diagnosed with pneumoconiosis and examined the relationship between whole blood metal levels and radiologic severity using the ILO classification system. Contrary to initial expectations, an inverse correlation was observed between blood metal concentrations and radiological profusion scores (r=–0.348, p=0.019), suggesting that workers with higher systemic metal levels exhibited milder radiographic findings.

The capacity of blood metal levels to reflect disease severity is complex and may not serve as a standalone indicator of exposure or disease progression. While systemic metal concentrations reflect exposure in the workplace environment, they may not directly determine particle deposition and resulting lung injury. Moreover, individual metabolic variations, particle type, and effectiveness of protective measures are important factors influencing the relationship between blood metal levels and pulmonary pathology.

There are significant differences between metal fume exposure occurring in high-temperature processes such as melting, casting, molding, and hot pressing, and silica dust exposure commonly seen in mechanical operations like grinding and sandblasting. Metal fumes consist of ultrafine metal oxide particles capable of systemic absorption, whereas silica dust comprises crystalline particles known to induce fibrotic changes in lung tissue.[5,6]

In our study, workers in units with expected high metal fume exposure generally exhibited milder radiological profusion scores despite the potential for systemic metal absorption. This may be explained by effective engineering controls and ventilation systems that reduce pulmonary deposition of harmful particles.[7] Moreover, metal fume exposure is more commonly associated with centrilobular ground-glass opacities on thoracic computed tomography, findings that are often less apparent on chest radiographs.[8]

Conversely, workers in units with high silica and mineral dust exposure, such as sandblasting and grinding, showed more severe radiological abnormalities. Although these mechanical processes do not generate metal fumes, they produce respirable crystalline silica and ultrafine particles, which may not be reflected in biological marker measurements but possess high fibrogenic potential, leading to significant lung damage.[9,10]

Furthermore, reliance on blood metal levels as sole biomarkers of exposure is increasingly questioned. Individual metabolic differences, physicochemical characteristics of particles, and sampling timing can all distort the correlation between systemic metal burden and pulmonary pathology.[11]

The observed positive correlation between profusion score and opacity size ($r=0.335$, $p=0.025$) aligns with previous studies indicating that radiologic progression accompanies increasing disease severity.[12]

Notably, no significant associations were found between disease severity and either cumulative work duration or smoking pack-years. This may reflect homogeneity of occupational tasks within the cohort or the predominance of acute or intermittent exposures over cumulative exposure metrics in disease progression.[13,14]

Overall, these findings emphasize that pneumoconiosis is a multifactorial disease influenced by dust type, particle behavior, exposure environment, protective measures, and genetic susceptibility.[15,16] Therefore, exclusive reliance on blood metal monitoring may fail to adequately capture risk, particularly in settings with mixed or non-metallic dust exposures.

CONCLUSION

Among foundry workers diagnosed with pneumoconiosis, whole blood metal levels exhibited a paradoxical inverse relationship with radiological disease severity. Workers in high-metal exposure units generally presented with milder radiologic findings, which may be due to the less conspicuous radiological manifestation of metal oxide particles in the lungs. In contrast, workers in units with presumed lower metal exposure frequently demonstrated more advanced disease, potentially linked to exposure to non-metallic particulates such as crystalline silica.

These findings underscore the critical need for a comprehensive occupational health surveillance approach that goes beyond conventional biomonitoring. Accurate risk identification and prevention require integrating detailed, task-specific exposure assessments and regular radiological evaluations, especially in work environments characterized by complex or mixed dust exposures.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study has been approved by the Scientific Researches Ethics Committee of Eskişehir City Hospital (Date: 25.06.2025, Decision No: ESH/BAEK 2025/201).

Informed Consent

Because the study was designed retrospectively, no written informed consent form was obtained from patients.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

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Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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