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Assessment of Spirometric Interpretation Methods: A Comparison between Percent Predicted and GLI 2012 among Workers in the Silver Industry

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Abstract

Background: Occupational exposure to fine particulate matter ($PM_{2.5}$) in small-scale silver industries increases the risk of respiratory impairment. Spirometry is widely used to assess lung function, but differences in interpretation methods may affect diagnostic accuracy. The conventional percent predicted (%Pred) method is still commonly applied, although the Global Lung Function Initiative (GLI) 2012 recommends a Z-score–based approach.
Objective: This study compared lung function classification using the %Pred method and the GLI 2012 Z-score approach among silver industry workers.
Methods: This analytical cross-sectional study involved 33 workers from large-scale and home-based silver industries. Spirometry measured forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), and FEV_1/FVC ratio. Lung function was classified using both %Pred and GLI 2012 methods. Differences and agreement were analyzed using the McNemar test and Cohen's Kappa.
Results: The GLI 2012 method detected a higher proportion of restrictive impairment (36.4%) than the %Pred method (21.2%). Six workers (18.2%) were reclassified from normal (%Pred) to abnormal (GLI). A significant difference was found between methods ($p = 0.041$), with moderate agreement ($\kappa = 0.586$). No obstructive pattern was identified.
Conclusion: The GLI 2012 Z-score method is more sensitive in detecting restrictive lung impairment than the %Pred approach. The %Pred method may underestimate abnormalities. Adoption of GLI-based interpretation can improve accuracy in occupational respiratory assessment.

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Introduction

Micro, small, and medium enterprises (MSMEs) constitute a fundamental pillar of economic activity in many developing countries, accounting for more than 90% of all business units and

spanning diverse productive sectors, from household-based crafts to small-scale manufacturing (ILO, 2023). Within this sector, home-based industries represent one of the most rapidly expanding components of the informal economy, providing livelihoods for millions of workers. However, these enterprises often operate outside formal occupational health and safety regulations, resulting in limited protection against workplace hazards. Despite their economic importance, production processes in home-based industries frequently generate hazardous airborne pollutants that pose significant risks to workers' respiratory health. In silver-processing industries, core activities such as smelting, grinding, cutting, polishing, and soldering release fine particulate matter ($PM_{2.5}$) enriched with metallic elements, including silver–copper–zinc (Ag–Cu–Zn) alloys. These particles can remain suspended in the air and are readily inhaled during routine work, contributing to cumulative respiratory exposure (Tran et al., 2024). Evidence from environmental and occupational studies indicates that chronic exposure to fine particulate matter is associated with reduced lung function and increased risk of obstructive airway diseases (Jung et al., 2017; Vinnikov et al., 2023).

In addition to particulate exposure, silver soldering generates complex chemical hazards. The thermal decomposition of flux materials releases ultrafine particles, volatile organic compounds (VOCs) such as formaldehyde and other aldehydes, rosin (colophony) fumes, and gases including carbon monoxide (CO) and carbon dioxide (CO_2). These emissions have been linked to airway inflammation, respiratory sensitization, and progressive decline in pulmonary function among exposed workers (Li et al., 2020; Tran et al., 2024). Such risks are particularly concerning in poorly ventilated home-based work environments, where exposure concentrations may exceed recommended limits. Spirometry is widely used in occupational health surveillance as a non-invasive tool to assess and monitor lung function. Key parameters, including forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC), are used to classify pulmonary function into normal, obstructive, restrictive, or mixed patterns. However, the validity of these classifications depends heavily on the interpretation method applied.

Traditionally, spirometry results have been interpreted using the percent predicted (%Pred) approach, in which measured values are compared to reference values adjusted for demographic characteristics, with a fixed threshold (commonly 80%) used to define normality. Although simple and widely implemented, this method has important limitations. It does not adequately account for the natural variability of lung function across age groups, body size, sex, and ethnic backgrounds, potentially leading to systematic misclassification of respiratory impairment (Hoet et al., 2017; Rahman et al., 2024; Struchkov et al., 2021; Kameneva, 2022). To overcome these limitations, the Global Lung Function Initiative (GLI) introduced standardized reference equations in 2012 based on a large, multi-ethnic dataset. Using the Lambda-Mu-Sigma (LMS) model, the GLI framework generates Z-scores that quantify deviation from the population median while accounting for age, sex, height, and ethnicity. Values below the lower limit of normal (LLN), defined as a Z-score < -1.64, are classified as abnormal. This approach has been endorsed by the American Thoracic Society (ATS) and the European Respiratory Society (ERS) as the preferred standard for spirometry interpretation, as it reduces bias and improves diagnostic accuracy (Quanjer et al., 2012; Doiron et al., 2019; Ong-Salvador et al., 2024; Kanj et al., 2023). Nevertheless, in many low- and middle-income countries, particularly in field-based occupational settings, spirometry devices and practices still rely on the %Pred method. This discrepancy in interpretation approaches may lead to inconsistencies in diagnosing respiratory impairment, including potential overestimation or underestimation of disease burden (Kitazawa et al., 2022; Mangseth et al., 2022). Several studies have highlighted that reliance on fixed cut-off values increases the risk of misclassification, particularly in populations exposed to environmental or occupational pollutants (Lam et al., 2025; Mizutani et al., 2023).

Given the high exposure to airborne contaminants in home-based silver industries and the methodological limitations of conventional spirometry interpretation, there is a need to reassess lung function classification using more robust standards. Therefore, this study aims to re-evaluate

spirometry data from workers in the silver craft industry using the GLI 2012 reference equations and to compare the results with those obtained using the conventional percent predicted method. This comparison is intended to quantify the extent of reclassification and to assess its implications for occupational lung health surveillance in informal industry settings (Won & Lee, 2022; Johnson & Johnson, 2022).

Materials and Methods

Study Design and Population

This study employed a cross-sectional design to assess the association between exposure to particulate matter ($PM_{2.5}$) generated from soldering processes and lung function among silver craft workers. A total of 33 workers were recruited from three large-scale companies and three home-based industries.

Inclusion criteria comprised all active workers involved in silver-processing activities. Exclusion criteria were expanded to reduce potential confounding factors affecting lung function, including: (1) history of congenital or physician-diagnosed asthma, (2) chronic respiratory diseases such as chronic obstructive pulmonary disease (COPD) or pulmonary fibrosis, (3) current acute respiratory infection, and (4) inability to perform acceptable spirometry maneuvers. Smoking status was recorded as a covariate but was not used as an exclusion criterion.

Demographic and Occupational Data

Data on key individual characteristics were collected, including age, sex, height, duration of employment, and smoking status. These variables are essential inputs for spirometric prediction models, particularly for Global Lung Function Initiative (GLI) calculations. A descriptive summary of participant characteristics was compiled to support the interpretation of spirometric findings. However, the absence of a detailed demographic table in this manuscript may limit the interpretability and reproducibility of the results.

Spirometry Procedure

Lung function was assessed using a portable spirometer (Spiro Analyzer ST-75). Measurements were conducted in accordance with general recommendations from the American Thoracic Society (ATS) and European Respiratory Society (ERS). Participants were examined in a seated position and performed at least three forced expiratory maneuvers, with the highest acceptable and reproducible values of FEV_1 and FVC recorded. Each maneuver involved maximal inspiration followed by rapid and forceful expiration. However, detailed documentation of device calibration, acceptability criteria (e.g., back-extrapolated volume), and reproducibility standards (e.g., ≤150 mL variability between maneuvers) was not available, which represents a methodological limitation.

Spirometric Parameters and Interpretation

Spirometry was used to obtain forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), and the FEV_1/FVC ratio. Lung function was interpreted using two approaches:

1. Conventional Percent Predicted (%Pred) Method
   Measured FEV_1 and FVC values were expressed as percentages of predicted values. A fixed threshold of <80% predicted was used to define abnormality. Restrictive patterns were defined as FVC <80% with a normal FEV_1/FVC ratio, while obstructive patterns were defined as FEV_1/FVC <0.7.
2. GLI 2012 Z-score Approach (Estimated)
   Lung function was also evaluated using Z-scores based on the Global Lung Function Initiative (GLI 2012), with the lower limit of normal (LLN) defined as $Z < -1.64$.

Estimation of GLI Z-scores (Important Limitation)

GLI 2012 Z-scores were not calculated using official GLI software due to the unavailability of complete Lambda-Mu-Sigma (LMS) parameters and lack of device integration. Instead, Z-scores were approximated using predicted values derived from spirometry output and published GLI reference equations. This approach does not fully capture the non-linear modeling and population variability inherent in the GLI framework and may introduce classification bias. Therefore, the resulting Z-scores should be interpreted as approximations rather than exact GLI-derived values.

Exposure Variable

Exposure to $PM_{2.5}$ from soldering fumes was treated as the primary independent variable. Workers were classified as exposed based on their involvement in soldering-related activities. However, quantitative measurements of $PM_{2.5}$ concentration were not performed, limiting the ability to assess dose–response relationships.

Data Analysis

Descriptive analysis was conducted to summarize spirometric parameters and classify lung function patterns (normal vs. restrictive). The proportion of workers classified under each category was reported, and differences between the %Pred and GLI-based approaches were explored to identify potential reclassification.

Statistical Analysis

Inferential statistical analysis was performed to assess differences and agreement between the %Pred and GLI classification methods. The McNemar test was used to evaluate differences in paired categorical outcomes. Agreement between methods was assessed using Cohen's Kappa coefficient. Statistical significance was set at $p < 0.05$. All analyses were conducted using statistical software.

Results and Discussion

Spirometric data were obtained from 33 workers employed in the silver craft industry using a Spiro Analyzer ST-75. Lung function was assessed using two interpretation approaches: the conventional percent predicted (%Pred) method and the Global Lung Function Initiative (GLI) 2012 Z-score method. Classification of ventilatory patterns followed established criteria: an obstructive pattern was defined by $FEV_1/FVC < 0.70$; a restrictive pattern by FVC below the lower limit of normal (LLN) with a normal FEV_1/FVC ratio; and a mixed pattern by a concurrent reduction in both FVC and FEV_1/FVC. Severity grading was based on FEV_1 as a percentage of predicted value, in accordance with the thresholds presented in Table 1.

Table 1. Classification of ventilatory impairment severity

Severity Level	Restrictive - FVC (% predicted)	Obstructive - FEV_1 (% predicted)
Normal	> 80%	> 75%
Mild	60–79%	60–74%
Moderate	30–59%	30–59%
Severe	< 30%	< 30%

Source: Adapted from ATS/ERS spirometry standardization guidelines.

Spirometric Values

The mean FEV_1 and FVC values of the study participants were 95.7 ± 14.8% and 87.9 ± 12.6% of predicted, respectively. The mean FEV_1/FVC ratio was within the normal range across the sample. No participant met the criterion for an obstructive pattern under either interpretation method.

Classification by the Percent Predicted (%Pred) Method

Using the conventional %Pred approach with an 80% FVC threshold to define normality, 26 out of 33 workers (78.8%) were classified as having normal lung function. The remaining 7 workers (21.2%) were classified as restrictive, all exhibiting FVC values between 60% and 79% of predicted, consistent with a mild restrictive pattern. The frequency distribution of FEV_1 values as a percentage of predicted is presented in Figure

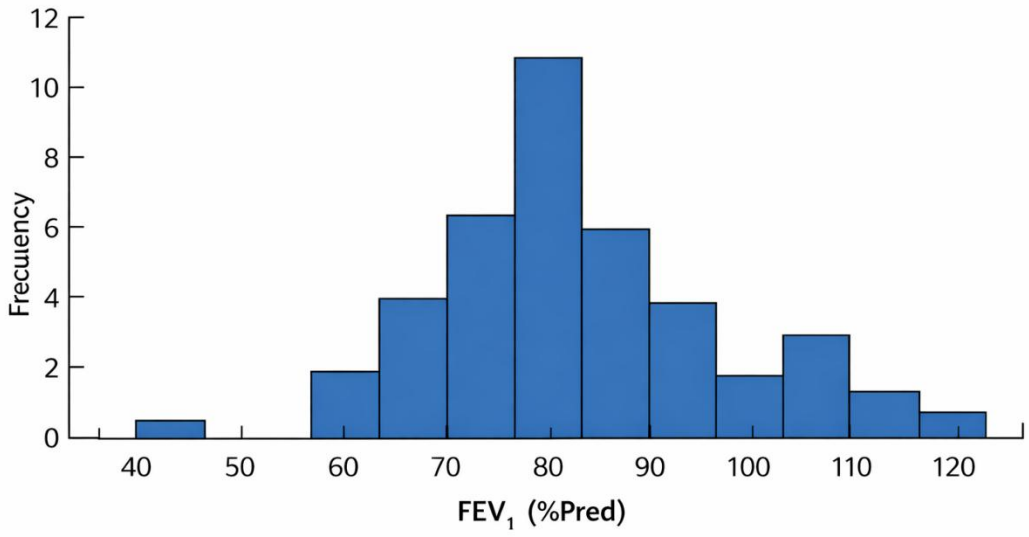

Figure 1. Distribution of forced expiratory volume in one second (FEV_1) expressed as percent predicted (%Pred) based on the conventional GOLD classification method among silver craft industry workers (n = 33).

Classification by the GLI 2012 Z-Score Method

Lung function was re-evaluated using GLI 2012 reference equations, with the Lower Limit of Normal (LLN) defined as a Z-score of −1.64 for both FVC and FEV_1/FVC. This threshold corresponds to the 5th percentile of the reference population and accounts for individual variability in age, sex, height, and ethnicity through the Lambda-Mu-Sigma (LMS) statistical model (Quanjer et al., 2012). Using this approach, 20 workers (60.6%) were classified as normal, 12 workers (36.4%) demonstrated a restrictive pattern (FVC Z-score < −1.64 with a normal FEV_1/FVC Z-score), and 1 worker (3.0%) exhibited a mixed pattern. No obstructive pattern was identified in any participant. The Z-score distributions for FVC and FEV_1/FVC are illustrated in Figures 2 and 3, respectively.

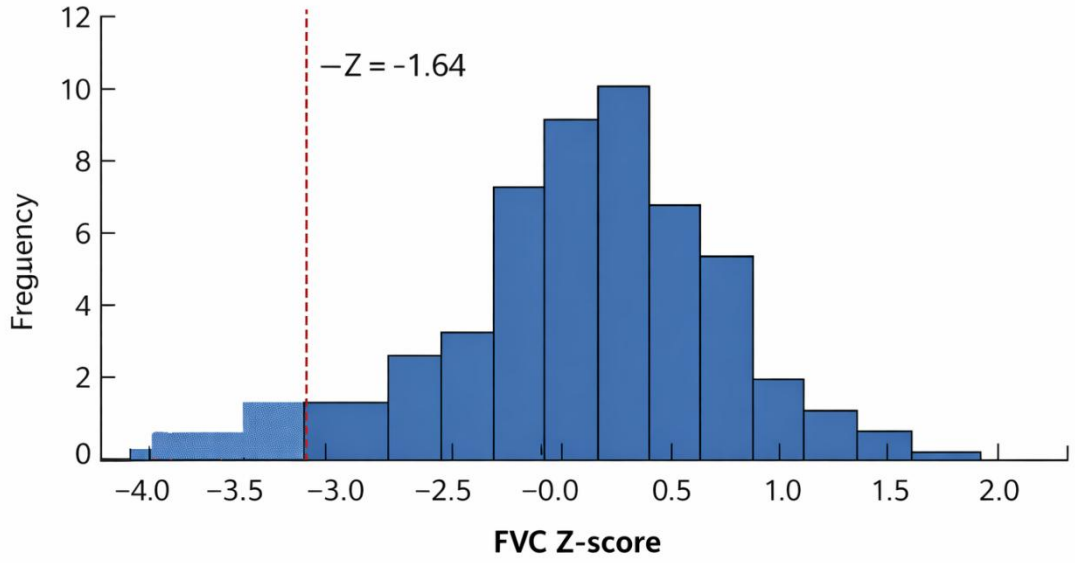

Figure 2. Distribution curve of forced vital capacity (FVC) Z-scores based on the Global Lung Function Initiative (GLI) 2012 reference equations among silver craft industry workers (n = 33). Values below the lower limit of normal (LLN; Z < -1.64) indica...

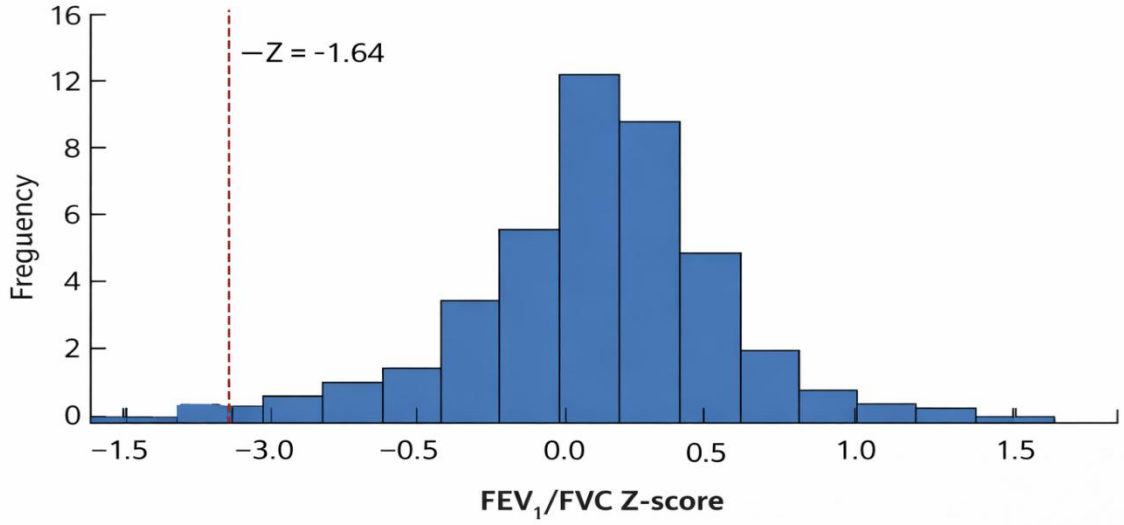

Figure 3. Distribution curve of respondents based on Z-score of FEV_1 /FVC. All values fall above the LLN (Z = -1.64), indicating no obstructive pattern.

Comparison and Reclassification Between Methods

A comparison of the two methods revealed a reclassification rate of approximately 18–25%. The GLI Z-score approach identified a substantially higher proportion of restrictive cases (36.4%) relative to the %Pred method (21.2%), representing a relative increase of approximately 72% in the detection of restrictive ventilatory impairment. The full classification outcomes from both methods are summarized in Table 2.

Table 2. Comparison of lung function classification: %Pred vs. GLI 2012 Z-score method (n = 33)

Ventilatory Pattern	%Pred Method n (%)	GLI 2012 Z-Score n (%)	Difference
Normal	26 (78.8%)	20 (60.6%)	−6 cases
Restrictive	7 (21.2%)	12 (36.4%)	+5 cases
Obstructive	0 (0%)	0 (0%)	-
Mixed	0 (0%)	1 (3.0%)	+1 case
Total	**33 (100%)**	**33 (100%)**	**-**

Note: Shaded rows indicate categories in which reclassification occurred between the two methods.

These findings indicate that the %Pred method underestimated the prevalence of restrictive lung impairment relative to the GLI 2012 standard. At least 6 workers (18.2%) were reclassified from normal to abnormal when the Z-score approach was applied, highlighting the clinical significance of the methodological choice in occupational spirometry interpretation.

Statistical Comparison Between Methods

The McNemar test showed a statistically significant difference between the %Pred and GLI classification methods ($p = 0.041$), indicating inconsistency between the two approaches in classifying lung function status.

Agreement analysis using Cohen's Kappa demonstrated a moderate level of agreement ($\kappa = 0.586$). This suggests that although there is some concordance between methods, a substantial proportion of cases were classified differently.

These findings confirm that the choice of interpretation method significantly influences the classification of lung function among workers.

Higher Detection of Restrictive Impairment Under GLI 2012

The primary finding of this study is that the GLI 2012 Z-score method identified a substantially higher proportion of restrictive lung impairment (36.4%) compared to the conventional %Pred approach (21.2%), with an overall reclassification rate of approximately 18–25% among silver craft workers. This discrepancy has direct implications for occupational health surveillance: workers classified as normal by the %Pred method may in fact have clinically meaningful reductions in lung function that warrant further clinical investigation and preventive intervention. This finding is consistent with evidence from the broader literature (Fontana et al., 2022; López et al., 2023). Elmaleh-Sachs et al. (2022) demonstrated in a large multi-ethnic cohort study that the %Pred method systematically misclassifies lung function status across demographic subgroups, particularly in populations whose characteristics are not adequately represented in the original reference dataset. Russell et al. (2025) further reported that Z-score-based indices show stronger associations with

adverse clinical outcomes including all-cause mortality compared to fixed percentage thresholds, supporting the potential clinical advantage of the GLI approach.

Methodological Basis for the Discrepancy

The fundamental difference between the two methods lies in how normality is defined. The %Pred method applies a uniform 80% cut-off for FVC regardless of the individual's demographic profile, derived from simplified linear regression equations based on limited reference populations. This approach does not accommodate the non-linear relationship between age and lung function and tends to over-classify older workers as normal because predicted values naturally decline with age and may misclassify younger workers in the opposite direction (Quanjer et al., 2012; Chang et al., 2025). In contrast, the GLI 2012 model employs the LMS (Lambda-Mu-Sigma) method, constructed from a diverse global dataset of more than 70,000 healthy non-smoking individuals spanning multiple ethnicities (Quanjer et al., 2012). The resulting Z-scores express each individual's measured value as a standardized deviation from the demographic-specific median. The LLN of Z = −1.64, corresponding to the 5th percentile, ensures that normality is defined consistently across all age, sex, height, and ethnic groups a statistical property that the fixed 80% threshold fundamentally cannot achieve (Ong-Salvador et al., 2024; Kanj et al., 2023). In the present study, the spirometric device used (Spiro Analyzer ST-75, developed circa 2010) outputs results primarily using the %Pred framework and does not include integrated GLI software. Consequently, GLI Z-scores were estimated from available predicted values using the published GLI 2012 reference equations rather than being derived from device-native LMS parameter tables. This constitutes an acknowledged limitation, as full precision requires device-integrated GLI calculations. Nevertheless, the directional findings remain internally valid and are consistent with previously published method-comparison studies in occupational settings.

Absence of Obstructive Patterns

Neither interpretation method identified obstructive ventilatory patterns in this cohort. This finding may reflect several factors: the relatively limited duration of occupational exposure among participants; the small sample size reducing statistical power to detect less prevalent patterns; or the predominance of $PM_{2.5}$-related restrictive effects over obstructive airway disease in this occupational context. Fine particulate matter ($PM_{2.5}$) and metallic fumes generated during silver smelting and soldering are known to primarily induce alveolar injury, interstitial inflammation, and parenchymal changes - pathophysiological mechanisms more consistent with a restrictive than an obstructive pattern (Li et al., 2020; Tran et al., 2024). The mixed pattern identified in one participant using the GLI method, but not detected by %Pred, further supports the contention that the conventional approach may fail to detect subtle, early-stage impairment.

Implications for Occupational Health Practice

The reclassification of approximately 6 workers from normal to impaired upon application of the GLI method underscores the risk of systematic underdiagnosis in occupational health settings that continue to rely exclusively on %Pred-based spirometry devices. In resource-limited environments such as home-based silver craft industries in Indonesia, this methodological gap can delay the identification of early-stage occupational lung disease and postpone essential preventive measures, including engineering controls, adequate ventilation, provision of respiratory protective equipment, and medical removal from hazardous exposure. The adoption of GLI-compatible spirometry software in field settings, or at minimum the post-hoc re-analysis of %Pred data using GLI reference equations, is therefore strongly recommended for occupational lung function surveillance programs in Indonesia and comparable settings (Al-Qerem et al., 2024; Roodenburg et al., 2024). This recommendation aligns with current guidance from the American Thoracic Society (ATS) and European Respiratory Society (ERS), and is increasingly acknowledged in Indonesian public health

policy, which recognizes the importance of ethnicity-appropriate reference values in pulmonary function testing (Silveyra et al., 2021).

Limitations

Several limitations of this study should be acknowledged. First, the sample size of 33 workers is relatively small, limiting both the generalizability of the findings and the statistical power to detect patterns of low prevalence such as obstructive or mixed impairment. A formal a priori power calculation was not conducted. Second, as discussed above, GLI Z-scores were estimated from available predicted values rather than computed using device-integrated LMS parameters, which may introduce minor imprecision in individual-level classifications. Third, the absence of detailed individual demographic and occupational exposure data - including years of service, duration of daily exposure, intensity of $PM_{2.5}$ exposure, and use of respiratory protective equipment - precluded a dose-response analysis between exposure intensity and the degree of lung function impairment. Fourth, the cross-sectional design prevents causal inference regarding the direction of the association between occupational dust exposure and spirometric abnormalities. Fifth, no formal statistical agreement analysis was performed (e.g., Cohen's Kappa, McNemar's test); such analyses should be incorporated in future studies to quantify the degree of discordance between interpretation methods. Future research should employ a prospective longitudinal design with larger, representative samples, complete GLI software integration, validated exposure assessment, and rigorous statistical methodology to build on these preliminary findings. In addition, the absence of multivariate analysis limits the ability to control for confounding factors such as smoking status and duration of exposure.

Conclusion

This study demonstrated differences in lung function classification between the conventional percent predicted (%Pred) method and the Global Lung Function Initiative (GLI) 2012 Z-score approach among silver craft industry workers. The GLI-based method identified a higher proportion of workers with restrictive lung impairment compared to the %Pred method, suggesting that the conventional approach may underestimate pulmonary abnormalities. However, the findings should be interpreted with caution due to several limitations. The Z-scores in this study were estimated using predicted values rather than calculated using full GLI LMS parameters, which may introduce measurement bias. Additionally, the relatively small sample size (n = 33) and the absence of quantitative exposure measurements limit the generalizability and strength of the conclusions. Overall, this study supports the potential value of adopting GLI-based interpretation for more accurate assessment of lung function in occupational settings, particularly in populations exposed to airborne contaminants.

The presence of statistically significant differences and only moderate agreement highlights the clinical implications of methodological choice in spirometry interpretation. The reclassification of workers from normal to abnormal suggests potential underdiagnosis when using the %Pred method. This finding is particularly important in occupational settings where early detection is critical for prevention.

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