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Employment Status and Lung Function Among Coal-Powered Electrical Plant Workers: A 5-Year Follow-up Study

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ABSTRACT

Background: Coal-powered electrical plant workers are exposed to coal dust in the entire work process. In South Korea, the processes with relatively high exposure to hazardous substances are mainly conducted by subcontractor employees. The harmful substances may cause pneumoconiosis, lung cancer, as well as a decrease in lung function. However, few studies have investigated changes in lung function among plant workers. The current study hypothesizes that the lung function of workers would be reduced by dust exposure and these reductions differ by employment status.
Methods: This study was conducted on 1,108 workers in coal-powered electrical plants who underwent lung function tests as a special health check-up from 2013 to 2018. The study population was divided into three groups according to the work they mainly perform. These groups were the contractor operator, subcontractor operator, and subcontractor maintenance worker. To compare the exposure level to hazardous substances, the exposure index was calculated with using the measurement data for the workplace environment. To confirm the change of lung function, this study used the repeated-measure analysis of variance.
Results: The subcontractor and the contractor had the highest and lowest exposure indices at 4.5 and 1.7, respectively. The lung function indicators significantly decreased among the subcontractor maintenance and operating workers compared with the contractor workers after 5 years. The pulmonary function with forced vital capacity (in liters) in subcontractors 1 and 2 decreased by 0.1 and 0.2 L, respectively. Forced expiratory volume in 1 second (in liters) also decreased in the subcontractors. In addition, the decrease in pulmonary function level over time differed according to each group because the interaction between time and employment status was statistically significant ($P < 0.01$).
Conclusion: These results suggest an association between coal dust and lung function deterioration. Also, differences in exposure can cause disparities in health outcomes even for workers in the same workplace.

Keywords: Coal Dust; Plant Workers; Respiratory Function Tests; Subcontractors

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INTRODUCTION

Coal-powered generators emit various pollutants (e.g., particulate matter, nitrogen oxides, and sulfur oxides). The main hazardous substances in coal-powered electrical plants are caused by coal. Moreover, power plant workers are exposed to coal or ash from unloading, transporting, storing, pulverizing, and combusting, as well as disposing of coal ash after being burned in the furnace.[1] Byproducts of coal combustion consist of small particles containing some heavy metals, radioactive materials, polycyclic aromatic hydrocarbons.[2-4]

The proportion of coal-powered electrical generation in South Korea was 39.7% in 2022 and occupies the largest portion of the total power generation. South Korea's dependency on coal-generated electricity is very high compared with other advanced countries excluding Australia, a major coal exporter, and Germany, a manufacturing powerhouse.[5]

Previous studies confirmed that coal dust is responsible for many diseases (e.g., emphysema, asthma, chronic obstructive pulmonary disease, pneumoconiosis, and lung cancer).[6-8] Some studies reported the associations between coal dust and cardiovascular diseases.[9,10] Most studies examining coal dust exposure and health effects have focused on miners and residents around coal-powered electrical plants. However, the literature on the health effects of workers in power plants is scarce. Also, understanding the exposure status of workers is difficult.

In coal-powered electrical plants in South Korea, the processes with relatively high exposure to harmful substances are mainly conducted by subcontractors and not by contractors. More hazardous work is performed by subcontractors even if they work in the same workplace. Thus, differences in exposure exist between employment statuses, which can lead to health disparities between workers. A study has shown that subcontractors experience significant illnesses and have a higher risk of work-related injuries than contractors.[11]

This study aims to identify the health impacts of coal on workers of coal-powered electrical plants by focusing on lung function and determining whether these health effects differed by employment status.

METHODS

Study participants

Since the data has been available since 2013, this study was conducted with workers in coal-powered electrical plants who underwent lung function tests as a special health check-up from 2013 to 2018. First, a list of subcontractors was obtained from the contractors. After confirming the management number of the subcontractors, examinees who received special health check-ups for dust from 2013 to 2018 were extracted using the management number. Applying the criteria described above, 2,349 and 3,307 participants were selected in 2013 and 2018, respectively. Among them, 1,108 workers who underwent a special health check-up in both 2013 and 2018 were selected as the final study participants. Additionally, we presented a **Supplementary Table 1** with more information about study participants in 2013 and 2018. **Fig. 1** shows the selection of study participants. This study used data from the Korea Occupational Safety and Health Agency (KOSHA) and Business (K2B) Service which are accumulated data of special health examination results for occupational hazards. This data

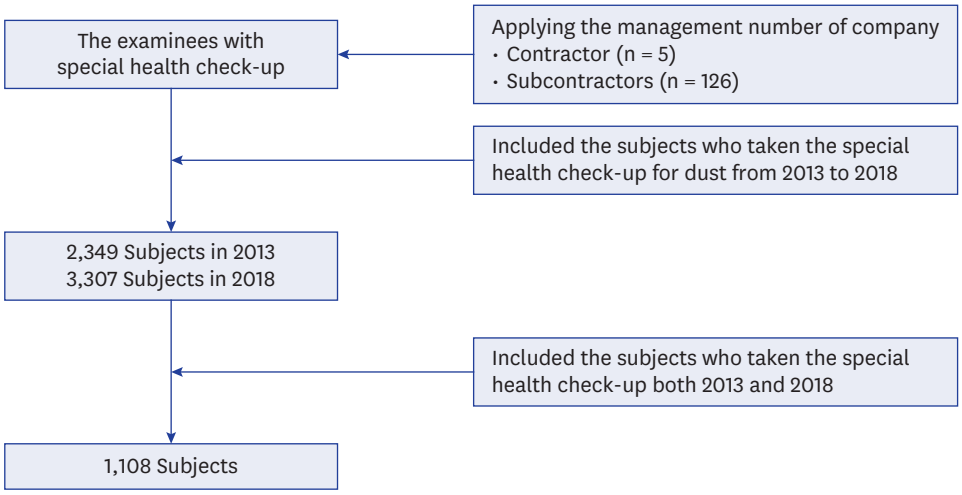


Fig. 1. Selection of study participants.

consisted of special health check-up year, management number of company, year of joining the company, type of occupational hazards, age, sex, social history, and medical test results.

The special health check-up was conducted by the employers to protect the health of workers exposed to occupational hazards. The employers were obligated to report the results of the special health examinations to KOSHA. This data was managed by the KOSHA's Department of Occupational Safety and Health Research Institute.

Employment status

A difference in exposure to occupational hazards exists depending on the kind of work the workers do at the coal-powered electrical plants. Thus, employment status was categorized into three groups. The groups were classified according to the work that the workers mainly do (i.e., contractor, in-house subcontractor 1, and in-house subcontractor 2). In-house subcontractor 1 and subcontractor 2 consist mostly of operators and maintenance workers, respectively. The contractors were in charge of operating the boiler and turbine, which are the core facilities in the plant. Most of the work was done indoors in the operations room. The contractors intermittently patrol the site to inspect related equipment. Exposure to coal dust may occur at this time, but the exposure frequency was not often. Subcontractor 1 was primarily responsible for maintaining power equipment and operating coal-related facilities and were significantly exposed to particulate matter (e.g., coal dust). Subcontractor 2 was in charge of the overall task of transporting, storing, and disposing of the ash after burning in the boiler. Subcontractor 2 was mainly responsible for the maintenance of the entire power plant process and was more likely to be exposed to ash dust and other hazardous substances than subcontractor 1.

Workplace environment measurement

The measurement data for the workplace environment as well as the results of the special health examination were reported to KOSHA. Assessment for individual exposure was not possible. Therefore, the measurement data for the workplace environment were analyzed using the K2B service from 2013 to 2018. This study used 10,260 sample data. Consequently, coal dust, welding fume, and wood dust were found as harmful factors for the respiratory system due to examining the measurement for the workplace environment. The values

marked non detection, trace, and below the detection limit were treated as 0. To compare the exposure level to hazardous substances in the workplace environment, the exposure index was calculated and compared using the formula

$$\text{Exposure Index (\%)} = \frac{\text{Exposure Concentration}}{\text{Exposure Standards}} \times 100$$

The final suggested exposure index was the average value for each employment status group after calculating the exposure index for each data. In addition to the exposure index by employment status, the exposure index by substance was shown in **Supplementary Table 2**.

Pulmonary function

The results of pulmonary function were extracted using the K2B services. The values such as forced vital capacity (FVC; in liters), FVC (in percentage), forced expiratory volume in 1 second (FEV1; in liters), FEV1 (in percentage), FEV1/FVC (in ratio), and peak expiratory flow (in liters per second), obtained from unprovoked pulmonary function test were acquired. Since 2002, the Occupational Safety and Health Research Institute has been conducting quality control to secure the reliability of pulmonary function test conducted by special health check-up institutions. Quality control is being implemented in accordance with the Korea Occupational Safety and Health Act. OSHRI has reviewed the results of pulmonary function tests performed by above all the institution every other year. Sample cases selected based on a combination of age, sex, and results. The cases submitted to OSHRI for evaluation. The following items are evaluated: appropriateness of equipment, laboratory environment, infection control, accuracy of results, description of testing methods, pre-test questionnaire, suitability, and reproducibility. Only the special health check-up institutions that pass these evaluation criteria are authorized to conduct special health check-up.

Statistical analysis

The distribution on sex, age, smoking status, amount of smoking, and tenure depending on employment status (e.g., contractor and in-house subcontractors) was confirmed. Percent predicted pulmonary function values (FVC and FEV1) were already adjusted for sex, age, anthropometric factors. Smoking status was adjusted for in all analyses. Also, the pulmonary function change over time between the contractor and in-house subcontractors in the coal-powered electrical plants was assessed using the repeated-measures analysis of variance (RM-ANOVA). The most important purpose of the RM-ANOVA was to test whether the interaction between time and group was statistically significant. Only subjects with complete data for both time points were included in the analysis. In addition, using this statistical method did not violate the assumption as there was no intervention over time in our study. To determine the magnitudes and directions of the interaction, the results of the pulmonary function test were analyzed by categorizing them into normal, obstructive and restrictive type. Generalized estimating equation methods were applied to find independent variables that influenced lung function outcomes in 2018. All statistical analyses were performed using the SAS version 9.4 (SAS Institute Inc., Cary, NC, USA), and statistical significance was confirmed by two-sided $P < 0.05$.

Ethics statement

This study was approved by the Institutional Review Board (IRB) of the International St. Mary's Hospital (IRB approval number: IS21EIMI0054). No informed consent was required from subjects due to the nature of public data from OSHRI.

RESULTS

The working process in coal-powered electrical plants is coal conveyance, storage, crush, boiler, turbine, desulfurization, and ash disposal. The company responsible for each process was different because it was impossible to undertake the entire working process in one company. Details are shown in **Fig. 2**. The operation of boilers and turbines, the most important facilities in a power plant, is carried out by contractor workers. The other processes such as maintenance, cleaning, and repair work is carried out by subcontracted workers. The detailed work duties of subcontracted workers and the hazardous factors to which they may be exposed are presented in a **Supplementary Table 2**.

Table 1 shows the airborne exposure indices which calculated the measurement for workplace environment in these plants. On the one hand, 5,839 samples were measured in the contractors' company. On the other hand, 4,421 samples were measured in the subcontractors' company. The subcontractor, task to maintain the general workplace, and the contractor had the highest and lowest exposure indices at 4.5 and 1.7, respectively. The difference in exposure index by work process was statistically significant ($P < 0.01$). When analyzing the difference in exposure levels between prime and subcontractors, we found that the average exposure index of subcontractors (3.7%) was more than twice as high as that of the contractor (1.7%). Both groups have low exposure levels. The exposure index by substance show that particulate matter has a higher exposure index than metals and other chemicals. Exposure indices for specific substances are presented in **Supplementary Table 2**.

The characteristics of the study participants are presented in **Table 2**. Most participants were men (98.3%) in their 30s (30.3%) and 40s or older (64.8%). The average smoking exposure was 11.6, 13.6, and 13.9 pack-years for contractor, in-house subcontractor 1, and in-house subcontractor 2, respectively. The proportion with ≥ 20 years in tenure was the highest at 40.3%. However, a difference in tenure was noted at 57.8%, 24.2%, and 67.7% for contractor, subcontractor 1, and subcontractor 2, respectively, when analyzed by employment status.

The pulmonary function comparison between the contractor and in-house subcontractors is shown in **Table 3**. In FVC (in liters), except for the contractors, subcontractors

Table 1. Combined exposure indices for respiratory hazard in coal-powered electrical plants

Company	Work process	No. of measures	Exposure index (mean)	Exposure index (max)
Contractor	Operation of power equipment	5,839	1.7	70.3
Subcontractor1	Operation of coal-related equipment	617	4.5	59.9
	Maintenance of power equipment	2,700	3.7	72.6
Subcontractor2	Maintenance of general workplace	1,104	3.3	86.1
P value				< 0.012

The *P* value was calculated by analysis of variance test.

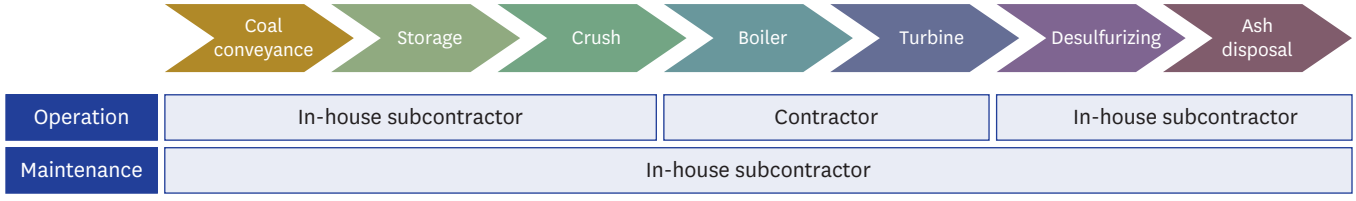


Fig. 2. The electricity production process and the company in charge in coal-powered electrical plants.

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Table 2. General characteristics of the coal-powered electrical plants workers (N = 1,108)

Variables	No.	Contractor	In-house Subcontractor 1	In-house Subcontractor 2
		Operator		Maintenance worker
Total	1,108	403 (36.4)	606 (54.7)	99 (8.9)
Sex				
Male	1,089	393 (97.5)	597 (98.5)	99 (100.0)
Female	19	10 (2.5)	9 (1.5)	-
Age, yr				
< 30	54	31 (7.7)	23 (3.8)	-
30–40	336	108 (26.8)	211 (34.8)	17 (17.1)
≥ 40	718	264 (65.5)	372 (61.4)	82 (82.8)
Smoking status				
Never-smokers	271	125 (31.0)	133 (21.9)	13 (13.1)
Ex-smokers	411	155 (38.5)	214 (35.3)	42 (42.4)
Smokers	426	123 (30.5)	259 (42.7)	44 (44.4)
Amount of smoking, pack-year		11.6 ± 10.3	13.6 ± 6.9	13.9 ± 9.1
Tenure, yr				
< 9	322	88 (21.8)	224 (36.9)	10 (10.1)
10–19	339	82 (20.3)	235 (38.8)	22 (22.2)
≥ 20	447	233 (57.8)	147 (24.3)	67 (67.7)

Values are presented as number (%) or mean ± standard deviation.

Table 3. The comparison of pulmonary function between contractor and subcontractors in the coal-powered electrical plants workers

Variables	Contractor (n = 403)		In-house subcontractor 1 (n = 606)		In-house subcontractor 2 (n = 99)		Group × time
	Operator				Maintenance worker		*P* value
	2013	2018	2013	2018	2013	2018	
FVC (L)	4.4 ± 0.6	4.4 ± 0.6	4.5 ± 0.7	4.4 ± 0.6	4.4 ± 0.6	4.2 ± 0.6	< 0.001
FVC (%)	92.1 ± 11.2	92.2 ± 10.0	94.2 ± 11.1	90.4 ± 10.6	96.8 ± 11.9	87.1 ± 10.3	< 0.001
FEV1 (L)	3.5 ± 0.5	3.5 ± 0.5	3.6 ± 0.5	3.5 ± 0.5	3.5 ± 0.5	3.4 ± 0.5	< 0.001
FEV1 (%)	96.1 ± 11.4	90.8 ± 10.9	94.7 ± 12.1	88.5 ± 10.8	98.9 ± 12.6	86.8 ± 10.1	0.011
FEV1/FVC (ratio)	81.2 ± 5.9	78.8 ± 6.0	89.0 ± 12.4	79.0 ± 5.8	80.9 ± 5.5	79.5 ± 5.4	< 0.001
PEF (L/sec)	9.1 ± 1.4	9.2 ± 1.7	8.9 ± 1.5	9.3 ± 1.6	9.1 ± 5.1	8.3 ± 1.4	0.007

Values are presented as mean ± standard deviation. Adjusted for age, sex, amount of smoking (pack-year).
FVC = forced vital capacity, FEV1 = forced expiratory volume in 1 second, PEF = peak expiratory flow.

1 and 2 decreased by 0.1 and 0.2 L, respectively. FEV1 (in liters) also decreased in the subcontractors compared with the contractors. In addition, the decrease in pulmonary function level over time differed according to each group because the interaction between time and employment status was statistically significant ($P < 0.01$). Further stratified analyses were performed on the smoking variable. **Supplementary Table 3** shows statistical significance was confirmed in the majority of variables, with the exception of FEV1 in non-smokers and peak expiratory flow in smokers.

DISCUSSION

The study confirmed that the pulmonary function of workers significantly became worse during 5 years. Differences in the changes of pulmonary function were noted in their employment status. Coal-powered electrical plant workers were exposed to elements harmful to the respiratory system. Also, these exposures were higher for subcontractors than for contractors.

This study showed that the degree of lung function decline differed according to employment status. Several reasons may cause this result. First, even workers in a similar workplace are exposed to different hazardous substances. The subcontractors work in a more

hazardous workplace than the contractors. Most of the work performed at coal-powered electrical plants, including maintenance or repair on facilities, is worked by subcontracted workers rather than the main contractors. Overhaul work which in intensively performed during a specific period or night maintenance work may have a high level of exposure to harmful substances. However, since work environment measurements often target regular work involving a majority of contractor workers, it is difficult to properly reflect the exposure levels of subcontracted workers. Subcontracted workers are known not only to be exposed to coal dust, crystalline silica and metals, but also to be more exposed to welding fumes, organic compound, and gaseous substances during maintenance and repair work.[12] Second, differences in exposure management exist. Although fewer workers were working as contractors, the number of workplace measurements was higher than that of subcontractors.[12] The workplace is owned by the contractor, but the contractor is negligent in managing it. Under the legal system, the contractor is responsible for workers and harmful exposure substances, but this is not the case in real world. In addition, Subcontractors lack abilities related to occupational safety and health, including management of harmful exposure. Subcontractors are presumed in a more difficult situation in identifying and managing hazardous substances compared to contractors. The risk is amplified when the outsourcing of risk and the lack of management meet. This amplified risk has a greater impact on subcontracted workers, who are in a relatively poor position.

Different employment statuses lead to different work environments. These differences also lead to differences in the risks associated with health and safety. Our research also confirmed that there are differences in exposure levels between contractor and subcontractors. Another study found that in-house subcontractors were more likely to handle hazardous chemicals than contractors. This difference in working conditions was also associated with a higher risk of occupational injuries.[13] A study using the Korea Work Environment Survey also found that in-house subcontracted workers were more likely to be exposed to occupational hazards and suffer from work-related accidents and illnesses.[11,14] In shipbuilding industries, in-house subcontractors have also been found to have vulnerable workplace conditions.[15,16] In addition to physically hazardous working conditions, complex subcontracting regimes,[17,18] lack of safety frameworks,[19] and lack of competencies[20] create differences in working conditions based on employment status, which in turn leads to health and safety issues.

This study has several limitations. First, selection bias may exist. The implementation of special health check-ups in South Korea may vary depending on the size of the company. Although workers often work in more dangerous settings in small companies compared with large companies, a tendency exists that small company owners will not conduct a special health check-up for their workers. This may have caused the results to be underestimated. The participants of the current study were limited to maintenance and operation workers. Other workers performing boiler dismantling operations with high dust exposure were not included in this study because they are usually excluded from special health check-ups. In addition, the possibility of selection bias exists for subcontractor 2, with an increased proportion of smokers compared to other contractors. However, if we assume that there is no interaction between employment status and smoking, the results of the study lead ‘to the null’ when ‘smoking’ is selected more. Therefore, the association between employment status and the change of lung function may be underestimated. Second, information bias may exist in the results of the lung function tests. The quality control for the lung function test is conducted by OSHRI to ensure reliability. The fitness rate for lung function tests increased from 72% to 91% in 2002 and 2018, respectively.[21] In general, the reliability of

the lung function test is secured. Nevertheless, some of the results suggest a lack of quality control of lung function. Therefore, the quality of pulmonary function tests should be further considered in future relevant studies. However, some variations may exist because the hospital where the test was conducted varies. Thus, predicting whether current study results have been overestimated or underestimated due to information bias is difficult.[22]

This study has drawn meaningful findings although some limitations were noted. The study is novel because follow-up studies on the respiratory health of dust-exposed workers are very rare. The discussion in society still focuses on mortalities when discussing the differences of health problems by employment status or outsourcing of risk. However, this study is believed to be the first in South Korea to show that clinical results were used to explain the health gap by employment status in power plant workers. Thus, differences in health problems can be made by differences in exposure even in the same workplace. This is the most significant finding of the current study. The health problems of coal-powered electrical plant workers have been underestimated. However, a long-term follow-up study is needed in the future to specify their health problems and to protect their health. Also, social efforts are needed to solve these health gap according to employment status.

SUPPLEMENTARY MATERIALS

Supplementary Table 1
Distribution of study subjects in 2013 and 2018

Supplementary Table 2
Exposure index for hazardous materials

Supplementary Table 3
The comparison of pulmonary function between contractor and subcontractors in the coal-powered electrical plants workers: stratified by smoking status

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