

Research Article



Related factors for preserving firefighter's pulmonary function

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Abbreviations

BMI: body mass index; COPD: chronic obstructive pulmonary disease; FEV₁: forced expiratory volume in one second; FFMI: free fat mass index; FVC: forced vital capacity; hSMI: height-adjusted skeletal muscle mass index; PEF: peak expiratory flow; SMI: skeletal muscle mass index.

ABSTRACT

Background: Firefighters are constantly exposed to harmful substances in the respiratory tract and require management measures. We comprehensively compared factors affecting the lung function of firefighters to identify management measures that can reduce the deterioration of lung function.

Methods: A cross-sectional study was conducted in 1,108 male firefighters. Subjects were surveyed with self-written questionnaires that included a history of smoking, number of workouts per week, work department, and medical history, including diseases that could affect lung function. Body mass index was calculated using an automatic body measurement instrument and body fat, body fat percentage, muscle mass, and skeletal muscle mass were measured using Inbody 770. Based on the body weight obtained from body measurements, skeletal muscle mass height-adjusted skeletal muscle index (hSMI) compared to height was determined. For lung function, forced expiratory volume in one second (FEV₁), forced vital capacity (FVC), FEV₁/FVC, and peak expiratory flow (PEF) were measured using a spirometer HI-801. Analysis of variance and independent t-tests were performed for univariate analysis of factors that could affect lung function, and multiple regression analysis was performed for multivariate analysis.

Results: When the factors relating lung function were analyzed using regression analysis, FEV₁ was negatively correlated with age, body fat percentage, and duty year, positively with height and hSMI. FVC increased with height and hSMI, decreased with age, body fat percentage, and duty year. FEV₁/FVC was related with age, height, body fat percentage and working history. Height and muscle mass were analyzed as related factors on PEF. When the analysis was conducted on firefighters who exercised more than 3 times a week, working history had lower relation with FEV₁ and body fat percentage had no relation with FEV₁/FVC.

Conclusion: We suggest management measures to reduce body fat percentage and increase skeletal muscle mass to maintain lung function in firefighters.

Keywords: Firefighters; Pulmonary function test; Body composition

BACKGROUND

Firefighters are frequently exposed to high concentrations of irritating respiratory toxic gases [1]. The exposure to dust, fumes, and toxic substances causes inflammation of the lungs

Competing interests

The authors declare that they have no competing interests.

Author contributions

Conceptualization: Kim S, Chung I; Data curation: Lee MY, Kim S, Jeon YE, Ryu H; Formal analysis: Chung I, Kim S; Investigation: Kim S, Chung I; Writing - original draft: Kim S; Writing - review & editing: Chung I.

and bronchi, thereby increasing the prevalence of acute and chronic respiratory diseases and reducing lung function [2-4]. The types of hazardous substances generated during fire extinguishing cannot be accurately analyzed [5]. Therefore, in the health management of firefighters, it is difficult to prevent exposure, and measures that focus on early treatment or rehabilitation are more effective.

The American Thoracic Society recommends using race, age, gender, height, and living environment to predict lung function [6]. In Korea, age, height, and weight are used to predict lung function [7]. There are also a number of studies on body composition, body mass index (BMI), and lung function. It has been reported that body fat percentage was negatively correlated with forced expiratory volume in one second (FEV₁), and free fat mass index (FFMI) was positively correlated with forced vital capacity (FVC) and FEV₁ [8]. In adult populations without asthma, FVC decreased as BMI increased [9]. In a study using (skeletal muscle mass index; SMI), it was found that FVC, FEV₁, and peak expiratory flow (PEF) decreased when muscle mass decreased [10]. Other studies have determined that more physical activity lowered the probability of developing chronic obstructive pulmonary disease (COPD) and improved lung function [11].

Although there are many factors known to affect lung function, these are studies of the general population. The purpose of this study was to investigate factors that affect the lung function of firefighters to provide health management methods for those who do not have a clear management plan for occupational exposure.

METHODS

The study population was comprised of 1,551 firefighters (1,470 male; 81 female) who visited the occupational health facilities in Daegu in 2017. Of the 1,470 male firefighters, 1,220 who performed both InBody and lung function tests were selected. Patients with COPD, ischemic heart disease, and arrhythmia were excluded. Finally, 1,108 firefighters were selected, excluding 13 under-weights with small percentage.

The subjects completed a questionnaire for health checkups and reported smoking history, work department, number of exercises per week, and medical history. Smoking was divided into three groups: current smoker, ex-smoker, and non-smoker. Three choices were presented for the number of workouts per week: more than 3 times, 1-2 times, and 0 times. Duty year was divided into 3 groups: no work history in fire extinguishing department, less than 5 years in fire extinguishing department, and more than 5 years in fire extinguishing department. Height and body weight were measured with an automatic body measuring instrument. Body fat, body fat percentage, muscle mass, and skeletal muscle mass were measured by the bioelectrical impedance method using Inbody 770. Based on the body weight obtained from body measurements, height-adjusted skeletal muscle mass index (hSMI: skeletal muscle mass [kg]/square of height [m²]) was calculated relative to height.

Pulmonary test was conducted by a skilled person who completed the degree of lung capacity test management training. Pulmonary function test calibration was performed twice a day, and it was re-calibrated if there was a change in the environment, 3L syringes were used, and the error was less than 3%. Temperature and humidity were recorded during the examination, and HI-801 (CHEST.M.I., Inc., Tokyo, Japan) was used. In accordance with the quality control guidelines, adequacy and reproducibility are satisfied.

Statistical analysis was performed using version 25 of IBM SPSS statistics (IBM Corp., Armonk, NY, USA). Body fat percentage were divided into 2 groups of less than 25 and above, according to the criteria, and an independent t-test was performed to determine whether there was a significant difference in pulmonary function between the 2 groups. The difference in lung function according to the number of years worked, the smoking history, and the amount of exercise was evaluated by an analysis of variance. Multiple linear regression analysis was performed to evaluate the overall effects of the previously evaluated factors on lung function. The enter method was used. Height, age, body fat percentage, number of years worked, smoking history, and amount of exercise were independent variables. In regression test, age₂ was used as variable, which excluded duty years in fire-extinguishing department, to prevent collinearity. To see if related factors differ in the group that exercised a lot, linear regression was conducted on people who exercised more than 3 times a week. Amount of exercise was control variable and other variables were same. A *p*-value of less than 0.05 was considered statistically significant. This study was approved by the Institutional Review Board of Keimyung University Hospital (IRB No. 2020-04-110).

RESULTS

Epidemiologic characteristics of research subjects

The average age of firefighters in the study was 43.53 years old and the average height was 173.21 cm. Based on the percentage of body fat, 848 (71%) had less than 25% and 339 (29%) had more than 25%. In terms of smoking, 571 (51.4%) non-smokers accounted for the largest percentage, with 333 (30.0%) reporting they were previous smokers and 204 (18.4%) current smokers. A total of 537 (48.4%) people reported that they exercised regularly more than 3 times a week, 494 (44.5) who did 1 or 2 times, and 77 (6.9%) reported working out 0 times per week. When classified according to the number of years working in the fire department, 434 (38.9) had no work history, 308 (27.7%) worked for less than 5 years, and 368 (33.2%) worked for more than 5 years (**Table 1**).

Factors related with lung function

Age was negatively correlated with FEV₁, FVC, FEV₁/FVC, and PEF. Height was negatively correlated with FEV₁/FVC and positively correlated with FEV₁, FVC, and PEF. hSMI was positively correlated with FEV₁, FVC, and PEF (**Table 2**).

When the body fat percentage was higher, FEV₁ and FVC decreased, and FEV₁/FVC increased. Current smokers had higher FVC than non-smokers. FEV₁, FVC, PEF and FEV₁/FVC decreased for those who worked for more than 5 years in the firefighting department compared to those who had never worked or worked for less than 5 years. There was no significant difference in the mean between each group for exercise (**Table 3**).

Management plan of lung function through regression analysis

A regression analysis was performed on each pulmonary function item with independent variables, including age₂, height, body fat percentage, hSMI, smoking history, work history, and the amount of exercise as independent variables. It was able to make a proportional formula of FEV₁ based on age₂, height, body fat percentage, hSMI, and duty year. Age₂, body fat percentage, and duty year had a negative correlation with FEV₁ and height and hSMI had positive correlation. FVC also had a negative correlation with age₂, body fat percentage and duty year. But was positively related with hSMI and height. FEV₁/FVC was associated with

Pulmonary function related factors

Table 1. Characteristics of study subjects

Variables	Values
Age (years)	43.53 ± 8.84
Height (cm)	173.21 ± 5.25
Body fat percentage (%)	
< 25	848 (71.0)
≥ 25	339 (29.0)
hSMI (kg/m ²)	10.94 ± 0.89
Smoke	
None	571 (51.5)
Ex-smoker	333 (30.1)
Current smoker	204 (18.4)
Exercise	
3-7/week	537 (48.5)
1-2/week	494 (44.6)
None	77 (6.9)
Duty year of fire extinguishing	
None	432 (39.0)
Less than 5yrs	308 (27.8)
5yrs or more	368 (33.2)
PFT	
FVC (L)	4.28 ± 0.58
FEV ₁ (L)	3.43 ± 0.51
FEV ₁ /FVC	79.91 ± 5.79
PEF (L/sec)	8.92 ± 1.3

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

hSMI: height-adjusted skeletal muscle mass index; PFT: pulmonary function test; FEV₁: forced expiratory volume in one second; FVC: forced vital capacity; PEF: peak expiratory flow.

Table 2. Correlation analysis between age, height, hSMI and PFT

Variables	FEV ₁		FVC		FEV ₁ /FVC		PEF	
	r	p	r	p	r	p	r	p
Age	-0.527	0.000	-0.449	0.000	-0.272	0.000	-0.200	0.000
Height	0.501	0.000	0.589	0.000	-0.069	0.023	0.266	0.000
hSMI	0.186	0.000	0.213	0.000	-0.009	0.757	0.212	0.000

hSMI: height-adjusted skeletal muscle mass index; PFT: pulmonary function test; FEV₁: forced expiratory volume in one second; FVC: forced vital capacity; PEF: peak expiratory flow.

Table 3. Comparisons of FEV₁, FVC, FEV₁/FVC, PEF by group of smoke, body fat %, duty year of fire extinguishing, frequency of exercise

Variables	FEV ₁		FVC		FEV ₁ /FVC		PEF	
	Mean ± SD	p	Mean ± SD	p	Mean ± SD	p	Mean ± SD	p
Body fat percentage (%)		0.001		0.000		0.012		0.349
< 25	3.46 ± 0.51		4.35 ± 0.58		79.72 ± 5.42		8.90 ± 1.32	
≥ 25	3.33 ± 0.50		4.12 ± 0.55		80.60 ± 4.91		8.98 ± 1.25	
Smoke		0.068		0.025 ^a		0.322		0.852
Non	3.41 ± 0.52		4.25 ± 0.59		80.19 ± 5.07		8.94 ± 1.33	
Ex-smoker	3.41 ± 0.49		4.28 ± 0.58		79.65 ± 5.45		8.92 ± 1.28	
Current smoker	3.50 ± 0.50		4.38 ± 0.55		79.93 ± 5.63		8.88 ± 1.25	
Exercise		0.671		0.853		0.068		0.279
None	3.41 ± 0.51		4.28 ± 0.58		79.79 ± 5.03		8.85 ± 1.29	
1-2/week	3.43 ± 0.51		4.29 ± 0.57		79.98 ± 5.58		8.98 ± 1.32	
3 times or more/week	3.45 ± 0.55		4.25 ± 0.66		81.28 ± 5.02		8.99 ± 1.21	
Duty year of fire extinguishing		0.000 ^b		0.000 ^b		0.000 ^b		0.000 ^b
None	3.49 ± 0.52		4.35 ± 0.59		80.29 ± 5.54		8.95 ± 1.26	
Under 5years	3.50 ± 0.47		4.34 ± 0.54		80.77 ± 5.18		9.12 ± 1.25	
5 years or more	3.28 ± 0.51		4.15 ± 0.58		78.96 ± 4.92		8.72 ± 1.37	

Compared using independent t-test and analysis of variance.

FEV₁: forced expiratory volume in one second; FVC: forced vital capacity; PEF: peak expiratory flow; SD: standard deviation.

^aA post hoc by Bonferroni: current smoker > non-smoker; ^bA post hoc test by Bonferroni: 5 years or more <, none, under 5 years.

Pulmonary function related factors

age₂, height, body fat percentage and duty year. It tended to decrease with age₂ and height and had lower value in those who were worked in fire extinguishing department for more than 5 years. But when body fat percentage increased, FEV₁/FVC also increased. PEF was associated with height, muscle mass. PEF increased with increasing height and muscle mass (Table 4).

A regression analysis was performed to determine which independent variables affect lung function in groups with 3 or more weekly workouts. As a result of the analysis, duty year in fire extinguishing department for 0–5 years did not have relation with FEV₁. And higher body fat percentage was not related with FEV₁/FVC (Table 5).

Table 4. Results of regression analysis for predicting the PFT

Variables	FEV ₁		FVC		FEV ₁ /FVC		PEF	
	B	p	B	p	B	p	B	p
Age ₂ (non-firefighting)	-0.020	0.000	-0.017	0.000	-0.152	0.000	-0.005	0.286
Height	0.039	0.000	0.056	0.000	-0.116	0.000	0.056	0.000
hSMI	0.039	0.006	0.061	0.000	-0.192	0.283	0.244	0.000
Body fat percent								
< 25	Reference		Reference		Reference		Reference	
≥ 25	-0.086	0.002	-0.157	0.000	0.811	0.018	0.107	0.198
Smoking								
None	Reference		Reference		Reference		Reference	
Ex-smoker	0.025	0.364	0.058	0.056	-0.424	0.230	-0.028	0.746
Current smoker	-0.006	0.850	0.034	0.360	-0.823	0.054	-0.192	0.063
Exercise								
None	Reference		Reference		Reference		Reference	
1–2/week	-0.002	0.972	0.035	0.523	-0.862	0.172	-0.029	0.848
3 times or more/week	0.001	0.989	0.042	0.444	-0.896	0.159	-0.175	0.255
Duty year of fire extinguishing								
None	Reference		Reference		Reference		Reference	
Less than 5 years	-0.072	0.019	-0.083	0.013	-0.031	0.937	0.104	0.267
5 years or more	-0.253	0.000	-0.207	0.000	-2.094	0.000	-0.174	0.056

The *p*-value less than 0.05 (typically < 0.05) was considered as statistically significant.

PFT: pulmonary function test; FEV₁: forced expiratory volume in one second; FVC: forced vital capacity; PEF: peak expiratory flow; Age₂: (age)-(duty years in fire extinguishing department); hSMI: height-adjusted skeletal muscle mass index.

Table 5. Results of regression analysis for predicting the PFT among firefighters who exercise more than 3 times a week

Variables	FEV ₁		FVC		FEV ₁ /FVC		PEF	
	B	p	B	p	B	p	B	p
Age ₂ (non-firefighting)	-0.020	0.000	-0.019	0.000	-0.114	0.000	-0.006	0.417
Height	0.036	0.000	0.051	0.000	-0.113	0.009	0.053	0.000
hSMI	0.081	0.000	0.078	0.001	0.438	0.095	0.349	0.000
Body fat percent								
< 25	Reference		Reference		Reference		Reference	
≥ 25	-0.105	0.010	-0.158	0.000	0.441	0.378	0.037	0.764
Smoking								
None	Reference		Reference		Reference		Reference	
Ex-smoker	0.045	0.252	0.056	0.200	0.131	0.786	0.012	0.916
Current smoker	0.094	0.087	0.107	0.076	0.151	0.821	-0.142	0.387
Duty year of fire extinguishing								
None	Reference		Reference		Reference		Reference	
Less than 5 years	-0.082	0.071	-0.109	0.029	0.078	0.888	0.075	0.582
5 years or more	-0.238	0.000	-0.228	0.000	-1.317	0.014	-0.185	0.157

The *p*-value less than 0.05 (typically < 0.05) was considered as statistically significant.

PFT: pulmonary function test; FEV₁: forced expiratory volume in one second; FVC: forced vital capacity; PEF: peak expiratory flow; Age₂: (age)-(duty years in fire extinguishing department); hSMI: height-adjusted skeletal muscle mass index.

DISCUSSION

Firefighters are exposed to various types of harmful substances that are not completely prevented by wearing protective equipment; thus, there is a risk of reduced lung function [12]. In this study, it was shown that lung function decreased as the number of years working as a firefighter increased. This is consistent with previous studies that showed that firefighters had a chronic decrease in lung function at a faster rate than the general population [13,14]. As the reduction in lung function of firefighters is due to the exposure of respiratory toxic substances during firefighting, the factors that greatly contribute to reduced function include how often, how severely, and how long they are exposed to respiratory toxicants rather than personal factors [15]. As a countermeasure to reduce lung function, special checkups and safety training are currently being implemented, but additional measures are needed to prevent chronic lung function reduction.

As a result of this study, an increase in muscle mass increased FEV₁, FVC, and PEF and a decrease in body fat percentage helped increase FVC and FEV₁. FEV₁/FVC seemed to increase in higher body fat percentage, because FVC decrease more than FEV₁ when body fat percentage increase. In the regression analysis, the amount of exercise did not significantly affect lung function compared to muscle mass and body fat percentage. In addition, in this study, to establish health management goals by presenting the characteristics of the groups that exercise a lot, regression analysis was conducted in groups that exercise more than 3 times a week. When limited to firefighters who exercise regularly at least three times a week, duty year on fire extinguishing ranging for 0–5 years did not seem to related with FEV₁. This can be interpreted that controlling hSMI and body fat percentage can reduce lung function decrease when accompanied by regular exercise. And FEV₁/FVC did not increase in high body fat percentage group. Current smokers had higher FVC than non-smokers in this study, maybe because mean age of current smokers was 4 years younger than non-smokers (40 < 44). Overall, our results suggest that increasing muscle mass and decreasing body fat percentage, rather than increasing the number of simple exercises, are effective methods to manage the lung function of firefighters.

In this study, FVC, FEV₁, and PEF were judged as pulmonary functions and were considered the goals of management. FVC and FEV₁ are the most important indicators used in workers' health checks to judge the deterioration of lung function by harmful factors. PEF is a test commonly used to diagnose obstructive pulmonary function such as asthma. PEF, when administered to examiners without lung disease, demonstrates the lung volume and muscle strength of the exhalation [16,17]. Therefore, PEF can also be used to screen for lung function decline in asymptomatic firefighters.

In addition, hSMI was included as a judgment index to explore the correlation between muscle mass and respiratory function. The electrical resistance measurement method can quickly and easily measure muscle mass and is often used as a medical examination or health care tool. The measured muscle mass is affected by height or weight. The indicator designed for this is SMI. There are 2 types of SMI: hSMI, divided by height squared, and weight-adjusted SMI, divided by skeletal muscle weight. hSMI is known to be more relevant to muscle function, including cardiopulmonary endurance [18].

Physical activity increases lung function and is known to lower the probability of developing COPD. This is thought to be due to the anti-inflammatory and anti-oxidative effects that counteract the harmful effects of exposure to foreign substances [19,20]. Changes in body fat

percentage and respiratory muscle strength may also be viewed as mechanisms of the effect [21]. Some literature suggests that physical activity can only offset the reduction in lung function by exposure to external harmful substances such as smoking [11]. In this study, when grouped based on the number of exercises, there was no difference in the mean of pulmonary functions among the groups. This is thought to be due to the high body load of firefighters on duty, so the difference in the amount of physical activity between groups is not significant. It is necessary to encourage efficient exercise by specifying variables that can affect pulmonary function.

Studies have shown that FVC, FEV₁, and PEF improve as muscle mass increases in all age groups when the amount of exercise is controlled [10]. This is because if the total muscle mass is large, the respiratory muscles involved in the expansion and contraction of the lungs increase. In addition, a decrease in muscle mass increases the mediator of inflammation, and thus decreases the elasticity of the lungs [22]. These results are consistent with ours which showed that muscle mass and body fat percentage, rather than exercise count, were closely related to lung function. To achieve the target, it is essential to not only participate in repeated low-intensity exercises such as walking but also focus on strength and high-intensity exercises. Studies have shown that performing aerobic exercise along with weight training is more effective in developing endurance and strength in respiratory muscles [23]. It was also shown that FEV₁ and FVC improved when weight exercise was performed in people with reduced chronic airflow restriction [24]. Strength training induced an increase in motor function such as VO_{2max} and workload, even if there was no increase in lung function [25].

In the past, there have been cases showing management through respiratory muscle enhancement for occupational exposure to harmful factors in the respiratory system. There was a study that showed significant improvement in lung function after arm exercise was performed in a welder who was known to have reduced lung function by exposure to harmful substances in the respiratory system [26]. Also, in the textile processing field with high exposure to harmful substances, whole-body exercise using arms, including swimming, helped improve lung function [27].

According to a paper published in 2017, 47.2% of Korean fire stations operated a fitness room [28]. In addition, among firefighters in our study, 48.5% reported that they exercised more than 3–4 times a week and sweat for more than 30 minutes, 44.6% reported that they exercised less than 2 times, and 6.9% said they did not exercise. According to the 2018 National Living Sports Participation Survey, based on men in their 40s, the corresponding values were 29.9%, 31.9%, and 38.2%, respectively. It can be interpreted that firefighters are already doing a lot of physical activity and have high accessibility of exercise equipment.

In the United States, training programs involving interval training and strength training are recommended for firefighters. In Korea, fitness training for firefighters has been conducted since 1999, but it is still at a formal level [29]. To improve the cardiopulmonary function of firefighters and prevent injury, it is necessary to evaluate the physical characteristics of the individual and systematic management through exercise prescription. The exercise regimen is expected to have a great effect on firefighters who have a strong will to exercise.

This study has several limitations. First, recall bias may exist because the occupational history depends on the examinee's record. In addition, the firefighting department was divided into inside and outside work, but because they were not able to distinguish between the 2 at the time of the questionnaire and other departments were involved in extinguishing

fires when there was a shortage of personnel, we were not able to accurately determine the exposure history. Existing literature also states that the firefighter system in Korea lacks a clear classification of occupations, and frequently supports other departments or tasks as needed [30]. Second, the number of workouts were based on the current exercise frequency, not the cumulative exercise amount, so it may not reflect the exact exercise status. Third, because this study was cross-sectional, it was not known how much it affected the degree of lung function reduction. Quantitative studies are needed to investigate the effects of lung function reduction and intervention through follow-up.

This study was conducted to find a management plan for reduced lung function in firefighters. According to this study, the frequency of exercise did not significantly affect the maintenance of lung function. From the above results, managing muscle mass and body fat percentage can be used as a measure for improving lung function, and exercise prescription and guidance are considered to be effective as part of a health promotion program.

CONCLUSION

This study studied factors that is related with firefighters' pulmonary function. According to this study, muscle mass and body fat percentage were important factor to manage firefighters' pulmonary function. To reduce the deterioration of lung function in firefighters, it is essential to focus on reducing body fat percentage and increase skeletal muscle rather than simply increasing the number of exercises.

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