

Decreased Pulmonary Function Over 5 Years in US Firefighters

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Objective: To examine changes in pulmonary function over a 5-year period in US firefighters. **Methods:** Spirometry values from occupational medical examinations separated by 5 years (2009 to 2016) were examined from 662 career firefighters in Virginia. Predicted values and expected 5-year changes in one-second forced expiratory volume (FEV_1), forced vital capacity (FVC), and FEV_1/FVC were estimated using reference equations generated from the Third National Health and Nutrition Examination Survey (NHANES III) data. Paired *t*-tests were used to identify significant changes over time and between the observed and expected changes. **Results:** FEV_1 and FVC (percentage of predicted) decreased ($P < 0.001$) from $100.9 \pm 0.6\%$ to $92.3 \pm 0.5\%$ and $99.0 \pm 0.6\%$ to $91.9 \pm 0.5\%$, respectively. The observed decreases in FEV_1 , FVC, and FEV_1/FVC were two to four times greater ($P < 0.001$) than the expected decrease over 5 years. **Conclusion:** Increased efforts are needed to ensure respiratory protection for US firefighters to minimize their risk of pulmonary damage.

Keywords: firefighters, lung health, pulmonary function, spirometry

Firefighters are an important occupational group that are exposed to multiple inhalation hazards and for whom pulmonary function tests are recommended prior to employment and on an annual basis.¹ Pulmonary function tests provide objective and quantifiable measures of lung function and are used for multiple reasons, including: to monitor the effects of environmental, occupational or drug exposures; to assess risks of surgery; and to assist in evaluations performed before employment or for insurance reasons.² In 1974, The New England Journal of Medicine published a paper documenting impaired respiratory and pulmonary function among firefighters.³ The rate of loss in forced vital capacity (FVC) observed in these firefighters over a 1-year period was more than twice the decline expected in the general population. Further, the study demonstrated that the decreases in pulmonary function measures were significantly related to frequency of fire exposure. In the decades following the publication of this article, numerous studies reported on the acute and chronic decrements in one-second forced expiratory volume (FEV_1), FVC, FEV_1/FVC , and overall pulmonary function following acute and chronic exposure among US firefighters.^{4–13} Collectively, the decreased pulmonary function identified in these studies encouraged

more consistent use of respiratory protection, specifically the use of self-contained breathing apparatus (SCBA) within the fire service.^{9,14} Currently, the Occupational Safety and Health Administration (29 cfr 1910.134)¹⁵ and the National Fire Protection Agency¹⁶ provide guidance on the mandatory use of SCBA when operating within the Immediately Dangerous to Life and Health environment (IDLH).

While the use of SCBA during fire suppression operations has increased, there is a pressing need to remain concerned about the respiratory health and respiratory protection of firefighters. Modern fires are producing smoke and byproducts of combustion, including polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), di-(2-ethylhexyl) phthalate (DEHP), and polybrominated diphenyl ethers (PBDEs), that are far more toxic than the contaminants released from fires decades ago.^{17–23} Furthermore, there is evidence of increased risk of cancer in the fire service²⁴ and respiratory exposure is considered an important route for exposure to carcinogenic chemicals.^{20,22} Although SCBAs are now nearly ubiquitous across the US fire service, there is evidence that SCBAs are not routinely used during all phases of firefighting.^{9,25,26} Specific times when firefighters may be exposed to smoke and other hazards include working on the scene of a structure fire before entering the structure (ie, firefighters often do not don the facemask until they enter the structure) or after the fire has been suppressed while they are performing overhaul duties in the structure.

A recent systematic review of longitudinal changes in lung function in firefighters found high variability in the reported rates of decline, and the authors concluded that more evidence is needed on the effects of routine firefighting on lung function.²⁷ Therefore, the purpose of this study was to investigate changes in pulmonary function in a large cohort of career firefighters over a 5-year period using occupational medical records.

METHODS

A cohort of career firefighters ($n = 662$) from Virginia was examined based on records from occupational medical examinations that were performed between 2009 and 2016. The medical evaluations were conducted by an occupational health clinic that performs annual medical evaluations on a contract basis to a large county-wide fire department. The medical evaluations are consistent with the National Fire Protection Association's 1582 Standard on Comprehensive Occupational Medical Program for Fire Departments and include assessment of pulmonary function via spirometry.²⁸ To examine changes in pulmonary function over time within firefighters, the medical records of firefighters who had two examinations separated by 5 years (4 to 6-year range) were examined.

During the occupational examination, height and weight were recorded using a digital physician's scale and stadiometer. Current smoking status was not reported due to a smoking ban policy initiated prior to baseline in this cohort. Experienced technicians collected spirometry values from a standard spirometer.^{29,30} The technician had participants complete three to five technically adequate efforts, with efforts automatically graded by the software. The largest acceptable values were recorded for data analysis. Data from the questionnaire and medical examination were entered into a database by the clinic staff and a de-identified dataset was transferred by the occupational clinic to researchers in the First Responder Health and Safety Laboratory at Skidmore College. This protocol was reviewed and deemed to be exempt by the Skidmore College Institutional Review Board.

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Conflicts of Interest: None declared.

Clinical significance: The decreases in pulmonary function over 5 years in a cohort of career firefighters were two to four times greater than expected. Health care providers should track decrements in spirometry values to identify excessive changes and encourage the use of respiratory protection during all phases of fire suppression.

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TABLE 1. Baseline Descriptive Statistics of a US Firefighter Cohort (n = 662)

Age, y	38.1 ± 7.7
Sex (n, % male)	593 (90)
Race/Ethnicity (n, %)	
White	474 (72)
African American/Black	108 (16)
Asian	19 (3)
Hispanic	51 (8)
Other	10 (2)
Height, m	1.8 ± 0.8
Body weight, kg	88.9 ± 15.0
BMI, kg/m ²	28.0 ± 3.9
Time between examinations (y)	4.8 ± 0.6

Values are mean ± SD or n (%).

Age, sex, and race-specific spirometric reference equations generated from a cross-sectional national sample of asymptomatic lifelong nonsmoking adults (NHANES III) were used to calculate predicted values for FEV₁ and FVC.³¹ Baseline age and the time duration between examinations were used to estimate the expected change over time using the same spirometric reference equations from Hankinson et al.³¹

Paired *t*-tests were used to identify statistical differences in the observed changes in pulmonary measures over time and differences between the observed and the expected changes over time. McNemar's test of differences were conducted to identify statistical differences in the percentages of firefighters with observed FEV₁ and FVC below 80% and 70% of their predicted volume and FEV₁/FVC ratios below 70%. The cut-offs for spirometric measures were based on medical requirements for firefighters, and were not intended to identify individuals with medical conditions. The level of significance for all analyses was considered at *P* < 0.05 and was two sided for all tests. All analyses were conducted using Stata 15.1 (StataCorp, College Station, TX).

RESULTS

The cohort of firefighters was on average 38.1 ± 7.7 years of age at baseline, predominately male and Caucasian, and had a mean BMI (28.0 ± 3.9 kg/m²) in the overweight category (Table 1). Baseline values for FEV₁ and FVC were 100.9 ± 0.6% and 99.0 ± 0.6% of predicted values, respectively. Over the 5-year period, significant decreases in FEV₁ (-0.46 ± 0.02 L; *P* < 0.001), FVC (-0.44 ± 0.02 L; *P* < 0.001), and FEV₁/FVC (-2.1 ± 0.1%; *P* < 0.001) were found. Observed absolute 5-year changes and percent changes in FEV₁, FVC, and FEV₁/FVC were significantly greater than expected values (*P* < 0.001) (Table 2).

TABLE 3. Percentages of Firefighters With Pulmonary Scores Below Thresholds Over a 5-Year Period

Threshold	Time 1	Time 2	Difference % (95% CI)
	%	%	
FEV ₁ < 80% of predicted ^a	6.3	13.5***	7.3 (5.0, 9.6)
FEV ₁ < 70% of predicted	1.2	3.4***	2.2 (0.9, 3.6)
FVC < 80% of predicted	5.8	13.1***	7.3 (4.7, 9.9)
FVC < 70% of predicted	0.9	2.1*	1.2 (0.03, 2.3)
FVC ₁ /FVC < 0.7	2.4	4.6***	2.2 (0.8, 3.6)

FEV₁, one-second forced expiratory volume; FVC, forced vital capacity.
^aPredicted values were calculated using reference equations generated by Hankinson et al³¹ using NHANES III data.
 **P* < 0.05.
 ****P* < 0.001.

The percentage of firefighters with less than 80% of predicted FEV₁ significantly increased (*P* < 0.001) from 6% to 14%, and the percentage of firefighters with less than 70% of predicted FEV₁ increased from 1% to 3% (*P* < 0.001) (Table 3). The percentage of firefighters with less than 80% of predicted FVC significantly increased (*P* < 0.001) from 6.3% to 13.5% (*P* < 0.001) and the percentage with less than 70% of predicted FVC significantly increased (*P* < 0.001) from 0.9% to 2.1%. The percentage of firefighters with a FEV₁/FVC ratio less than 0.7 significantly increased (*P* < 0.001) from 2.4% to 4.6%.

DISCUSSION

The primary findings of this study are that pulmonary function in this large cohort of career firefighters significantly decreased over the 5-year period, and the observed decreases were two to four times greater than the estimated decreases that would be expected in the general population over a 5-year period.

There are known changes in the pulmonary system as individuals age, including alterations in the size of the thoracic cavity, limiting lung volumes, and altering the muscles that aid in respiration.^{10,31} However, the findings from the current study indicate that these age-associated changes were augmented in this cohort of firefighters and are consistent with research conducted on the fire service during the 1970s. A study of 1430 firefighters from the greater Boston area between 1970 and 1972 found significant decreases in spirometry values³ that are similar to the rate of decline in individuals with chronic obstructive pulmonary disease (~80 mL/yr).³² Furthermore, the loss of pulmonary function was associated with the frequency of fire exposure, with twice the loss among heavily exposed firefighters as compared with firefighters with light exposure.³ Additional studies have also shown decreases in spirometry values during active duty⁴⁻¹³

TABLE 2. Five-Year Changes in Pulmonary Measurements Among a Cohort of US Firefighters

	Time 1	Time 2	Change	Expected Change ^a	Change (%)	Expected Change ^b (%)
FEV ₁ , L	4.13 ± 0.03	3.67 ± 0.03	-0.46 ± 0.02*	-0.12*	-10.5 ± 0.3*	-3.1*
FEV ₁ (% of predicted)	100.9 ± 0.6	92.3 ± 0.5	-8.6 ± 0.5*	0	-7.8 ± 0.3*	0
FVC, L	5.03 ± 0.04	4.59 ± 0.03	-0.44 ± 0.02*	-0.10*	-8.2 ± 0.3*	-1.9*
FVC (% of predicted)	99.0 ± 0.6	91.9 ± 0.5	-7.1 ± 0.4*	0	-6.6 ± 0.4*	0
FEV ₁ /FVC (%)	82.2 ± 0.2	80.1 ± 0.2	-2.1 ± 0.1*	-0.98*	-2.5 ± 0.2*	-1.2*

Values are reported as means ± SE. FEV₁, one-second forced expiratory volume; FVC, forced vital capacity.
^aExpected change was calculated using reference equations generated by Hankinson et al³¹ using NHANES III data. Paired *t*-tests were used to compare expected change with the observed change.
^bPaired *t*-tests were used to compare expected change (%) with the observed change (%).
 **P* < 0.001

as well as during wildland firefighting³³ and work at the World Trade Center disaster.¹⁰

Heterogeneity and lack of excessive declines in pulmonary function in firefighters and associations with fire fighting duties have also been shown across cohorts.^{14,27,34,35} Studies observing the Boston Fire Department from the late 1970s to the early 1980s found that firefighters who were not engaged in active firefighting duty also had large reductions in both FEV₁ and FVC, suggesting that other factors besides fire and smoke exposure promoted respiratory and pulmonary ailments. Additionally, these studies showed that firefighters who transitioned to less active assignments also had a greater decrement in ventilatory capacity than those who remained in firefighting positions.³⁴ Some limitations in these studies, including the crude assessment and definition of exposure, as well as the limited number of subject responses, may explain the divergent findings.^{34,35} Furthermore, evidence suggests that some of these subjects were in fact retiring prematurely because of respiratory impairment, which could have significantly altered the findings.³⁵

More recently, a study in 2013 that investigated changes in pulmonary function over 5 years in NYC firefighters who were not exposed to the World Trade Center disaster found that the decline in FEV₁ among newly hired firefighters was not significantly different from a control group (EMS workers) over a 5-year period.³⁶ Firefighters in the Aldrich et al³⁶ study had a FEV₁ (98.8% of predicted) at the time of hire which is similar to the 100.9% of predicted FEV₁ that was found in the current study at baseline. However, the current study found an annual rate of decline in FEV₁ (92 mL/yr) that was about two times as large as the yearly decline (45 mL/yr) reported by Aldrich et al.³⁶ The current study sample was on average 12 years older than the firefighters in the Aldrich et al study,³⁶ and longitudinal decreases in FEV₁ are larger among older adults,³⁷ which might partially explain the difference in FEV₁ decline observed between the two cohorts.

In 1981, the NFPA required US firefighters to wear personal protective equipment (PPE) and SCBA.³⁸ Although the use of respiratory protection has become standard in the fire service, certainly in large career fire departments, the systematic use of SCBAs is arguably more important now than when first introduced due to the increasing toxicity of smoke in modern fires.³⁹ Unfortunately, there may be inconsistent and inadequate use of respiratory protection in the fire service. Research from 2001 suggests that SCBAs are used around 50% of the time during structural fires, yet only 6% of the time during all other types of fires.²⁶ Removal of SCBA prior to overhaul can result in exposure to respiratory toxins, asphyxiants, synthetic polymers, and smoke plumes on the foreground, which promote adverse health effects in firefighters.^{25,39} It is also possible that other factors, such as particulate matter from the diesel exhaust of rescue equipment, could affect spirometry values of firefighters. The use of respiratory protection is important in protecting against lung damage and decreases in pulmonary function, and may partially explain some of the heterogeneity in pulmonary decline across studies.²⁶ A systematic review of longitudinal changes in lung function among firefighters found non-smoking firefighters who routinely wore respiratory protection were more likely to have normal rates of decline in lung function.²⁷ Firefighters who reported “never or rarely” using their respiratory protection equipment during fire knockdown had a higher odds (odds ratio [OR]: 2.20; 95% confidence interval [CI]: 1.02 to 4.74) of accelerated FEV₁ decline (greater than 50 mL/yr) than those who “often or frequently” used their respiratory protection equipment.⁴⁰ The unprotected airway also provides an important exposure risk to carcinogens. Modest associations of firefighter exposure with lung cancer and leukemia mortality have been reported.²⁴ Excess malignant mesothelioma among firefighters has also been shown, suggesting a workplace asbestos hazard for firefighters given that asbestos is the only known causal agent for malignant mesothelioma.⁴¹

The results presented demonstrate that most of the firefighters examined had spirometry values that were in the upper range of normal and remained well within the normal range (more than 80% of predicted value) after 5 years, even though significant decreases were observed. However, over the 5-year period, significantly more firefighters had lung function that would have resulted in disqualification of a recruit firefighter, or additional testing and potential medical disqualification for a continuing member of the fire department. The increased percentage of firefighters not meeting clinical thresholds over the 5-year period is an important finding of this study. In addition, a decrease in lung function may be important even among firefighters whose lung function values remain within the normal range. An excessive decrease in lung function is an indication that respiratory protection was not being used as often or stringently as desired. Though not tested directly in this study, it is possible that the greater toxicity of smoke based on current home furnishings and other commercial exposures are creating an occupational exposure where even limited smoke exposure may result in decreased respiratory function. Monitoring changes in pulmonary function provides an opportunity for health care providers to discuss the benefits of respiratory protection, including decreased risk of pulmonary disease and cancer, with firefighters.

There are important limitations to note to provide context for the results found in this study. The findings presented are from one large fire department, a control group of non-firefighters from the same county were not observed, and fire exposure and use of respiratory protection was not recorded; therefore, the changes reported may not reflect the changes that occurred among firefighters at a national level. In addition, several studies have shown discrepancies between estimates of annual decline in pulmonary function between cross-sectional and longitudinal studies.⁴² Two large cohort studies showed that the longitudinal decline was smaller than what was predicted from cross-sectional analyses^{43,44} among younger subjects, and that this relationship was age-related and switched between 40 and 45 years of age.⁴⁴ Nevertheless, the extent to which the spirometric measures decreased in the current study were well above those observed longitudinally in the studies noted above and indicate that a higher than normal decrease in pulmonary function occurred in this cohort of firefighters during the 5-year period as compared with what would be expected in the general population.

CONCLUSION

A reduction in firefighter respiratory function two-to-four-times greater than the estimated decrease expected in the general population over a 5-year period was found among career firefighters. These findings provide evidence that more stringent use of SCBA is still needed to protect the respiratory health of firefighters. Respiratory protection should be used when firefighters are exposed to smoky conditions, such as on the fireground, or during overhaul activities when gas and particulate levels are elevated even if the air appears clear.

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