Occupational Health Surveillance: Pulmonary Function Testing in Utility Workers

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Abstract
This investigation analyzed occupational health monitoring data to characterize pulmonary function in a population currently employed as utility workers in the state of Florida. Pulmonary function tests for male workers (n=225) who required medical examinations to ensure fitness for continued respirator use were compared to National Health and Nutrition Examination Survey (NHANES) III Raw Spirometry subjects (n=4958) to determine if abnormal pulmonary function was associated with employment as a utility worker. Mean Forced Vital Capacity (FVC) and mean Forced Expiratory Volume in 1 second (FEV1) values were determined, and linear regression was used to evaluate the impact of utility worker status on pulmonary function after adjusting for confounders. Workers had a statistically significant higher total mean FEV1 value of 3.81L (95%CI 3.71–3.91), compared to the NHANES III mean value of 3.71L (95% CI 3.69–3.73). The total mean FVC value for workers 4.85L (95% CI 4.73–4.96) was also statistically significant compared to the NHANES III mean of 4.70L (95% CI 4.68–4.73). No significant differences were found between mean pulmonary function test values of utility workers and NHANES III study subjects when stratified by age, height, and smoking status except among older utility workers, who demonstrated modestly better FEV1 and FVC values compared to the study population. Multivariate regression analysis demonstrated that significant predictors of FEV1 included age, height, pack-years of smoking, and status as utility worker (all p-values<0.05). Significant predictors of FVC included age, height, and status as a utility worker (all p-values<0.05). Logistic regression analysis to evaluate associations with FEV1/FVC ratios<0.80 demonstrated significant associations with age, height, and smoking history, but not status as a utility worker. The results of this investigation did not find any pulmonary function deficits in the examined utility worker population. This study demonstrates the feasibility of using mandated occupational health monitoring data to conduct efficient occupational health surveillance.

Introduction
Airborne occupational exposures to irritants, vesicants, and fibrogens have the potential to cause pulmonary function impairment when exposures are not properly controlled over extended periods of time. For occupations where workers may be exposed to substances associated with pulmonary function impairment, respirators may be the principal method for exposure control, outside of local ventilation, product substitution and work practice controls. The Occupational Safety and Health Administration (OSHA) mandates that workers who must use respirators are required to undergo periodic pulmonary function testing to ensure that individual worker's lung function is adequate for respirator use [1]. Spirometry data collected as a result of this mandatory testing provide a unique opportunity to perform occupational health surveillance among workers in targeted industrial sectors known to have potentially harmful exposures in the workplace. Unfortunately, the vast majority of this data is used to simply validate individual capacity for respirator use and is ignored for population level analysis.

Pulmonary function testing is particularly well suited for occupational surveillance given the availability of the NHANES III Raw Spirometry data set, which allows for population level analysis of worker spirometry data to be compared to a standard population adjusted for age, height, tobacco smoking, and other factors that impact pulmonary function not related to the occupational environment. The NHANES III Raw Spirometry data contain over 15,000 individual spiromograms matched to standard NHANES demographic and survey data. Once compiled, mandatory pulmonary function data from exposed workers can be quickly analyzed for comparison to NHANES III data to determine if a population level abnormality exists within a specific industrial sector [2].

In Florida, fossil fuel power generation is used to provide electricity to sustain commercial, agricultural, and residential needs. Operations involved in these power plants include coal handling, boiler-turbine operation, and maintenance. Utility workers that perform these operations have the potential to be exposed to chemicals in the workplace that can affect pulmonary function. For example, coal handling includes coal receiving, storage, and recovery for fueling the turbine generator units and leads to certain tasks which are associated with high coal dust air levels and require respiratory protection [3]. During boiler maintenance, cleaning, and repair, workers can be exposed to fossil fuel ash particles. Hauser et al. [4] conducted a two-year longitudinal study of lung function among 118 boilermakers and found that working at gas, oil, and coal-fired plants is associated with an annual loss in FEV1. Bridbord et al. [5] identified a number of irritants, vesicants, and fibrogens within coal-fired power plants which included sulfur dioxide (SO2), SO2 reaction products, nitrogen oxide (NO), nitrogen dioxide (NO2), fly ash, aldehydes, coal dust, and asbestos. Potential sources of these chemicals included boiler leaks, flue gas leaks, stack emissions, all stages of coal handling, and insulation material. Over 65% of SO2 released to the air, or more than 13 million

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tons per year, comes from electric utilities, especially those that burn coal [6]. The United States Department of Labor has identified SO₂ as a respiratory irritant and indicates that studies have shown increased pulmonary resistance at various concentrations [7]. As the working environment of utility workers is often subject to exposures exceeding regulatory levels, respirator use is required for workers performing their job in high exposure environments. In order to evaluate the use of required pulmonary function testing in workers who use respirators, the current investigation analyzed health monitoring records for seven utility companies in the state of Florida with required respirator use. The feasibility of analyzing OSHA mandated pulmonary function testing data as a tool for occupational health surveillance is explored.

Methods

A record review was conducted on 225 pulmonary function tests from a population currently employed as utility workers in the state of Florida. Inclusion criteria included any worker over the age of 18 whose respirator use required pulmonary function testing. Records included data for principal confounding factors regarding pulmonary function outcomes including smoking history, age, gender, and height. A standard population for comparison consisted of the NHANES III Raw Spirometry cohort, which consists of pulmonary function tests for 16,606 individuals. The Raw Spirometry file was merged by respondent identification number with NHANES III Household Adult Data file to obtain demographic and behavioral confounder data. The NHANES control population was further restricted by age to reflect the age range of the study population (19–59 years) and unacceptable tests were removed from analysis by technician quality code resulting in a final control population of 4,958 subjects. There were only two females in the worker population; therefore females were removed from both the worker and NHANES population for analysis. Record reviews were approved under the University of South Florida Institutional Review Board # 00001348.

All study population pulmonary function testing was conducted using the Koko spirometry system. The best attempt of a minimum of three spirometry trials was used for analysis in both the study population and the control population. The pulmonary function test outcomes used for analysis included FEV₁ and FVC. All results are expressed as liters (L). All spirometers were reviewed by a licensed physician and spirometers not meeting American Thoracic Society acceptability and reproducibility criteria were removed from analysis.

To determine if the utility worker population experienced abnormal pulmonary function compared to the standard population, mean values were produced for FEV₁ and FVC and the significance of the differences were evaluated using the Student's t-test. These analyses were further stratified by median age, median height, and smoking history. To determine which factors were most predictive of pulmonary function, multivariate regression analysis was performed for the outcomes of FEV₁ and FVC. Multivariate analysis evaluated the following variables as predictors of pulmonary function outcomes: age, height, pack-years of smoking, and status as a utility worker.

There is currently an active debate regarding the use of the FEV₁/FVC ratio as a definitive criterion for the diagnosis of obstructive disorders, but it is generally acknowledged that lowered FEV₁/FVC ratio is indicative of obstruction when taken into context with other pulmonary function testing data for the individual and patient demographics [8]. In the current investigation, we evaluated the study population for deficits at the higher end of the normal FEV₁/FVC range, 0.80. A categorical approach was used to evaluate potential predictors of clinical pulmonary obstruction using logistic regression to evaluate associations with producing an abnormal FEV₁/FVC ratio, defined as less than 0.80. Categories for independent variables were defined as above and below median height and median age, females vs. males, non-smokers vs. those with a smoking history. Statistical significance was determined by p < 0.05 for all analytical tests. All statistical analyses were performed using SAS version 9.1.2.

Results

Univariate analysis

The population demographics for both the study population (utility workers) and the NHANES III segment used for analysis are reported in table 1. The study population consisted of only males and approximately 41% had a history of tobacco smoking. The study population was slightly older overall, compared to the NHANES III mean age (45 and 41 years respectively).

Table 2 provides the results of means testing for FEV₁ and FVC comparing the total study population to the NHANES III segment. The study population demonstrated a modestly higher mean FEV₁ and FVC compared to the NHANES III population. The differences in age, height, and smoking history represented in the study population necessitated the use of stratified analysis to determine the effect of these population differences on evaluating the effect of utility worker status on pulmonary function.

Stratification by age, height, and smoking status did not yield statistically significant larger mean values for FEV₁ and FVC measurements for the study population except among older utility workers, who demonstrated modestly better FEV₁ and FVC values compared to the NHANES III population. The results of the analysis are reported in table 3.

Multivariate analysis

Multivariate analysis was conducted by constructing linear regression models including all data elements known to impact pulmonary function including age, height, and smoking history. The parameter estimates identify the magnitude of effect each predictor has on either increasing or decreasing pulmonary function in the total population.
p-value 0.0848

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at test</td>
<td>-0.03168</td>
<td>0.00169</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Height at test (in)</td>
<td>0.11685</td>
<td>0.00583</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Smoking History (pk-yrs)</td>
<td>-0.00314</td>
<td>0.00107</td>
<td>0.0034</td>
</tr>
<tr>
<td>Utility Worker Status</td>
<td>0.30053</td>
<td>0.04526</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Table 4: Predictors of FEV1 from Linear Regression Analysis.

**FVC**

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>p-value</th>
</tr>
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<tbody>
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<tr>
<td>Height at test (in)</td>
<td>0.11685</td>
<td>0.00583</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Smoking History (pk-yrs)</td>
<td>0.00199</td>
<td>0.00128</td>
<td>0.1221</td>
</tr>
<tr>
<td>Boat Manufacturer Status</td>
<td>0.24602</td>
<td>0.05425</td>
<td>&lt;0.0001</td>
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</table>

Table 5: Predictors of FVC from Linear Regression Analysis.

**FEV1/FVC <0.80**

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Odds ratio</th>
<th>95% Confidence Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age above median &gt;29 years</td>
<td>3.86</td>
<td>3.39 - 4.40</td>
</tr>
<tr>
<td>Height above median &gt;67 inches</td>
<td>1.48</td>
<td>1.30 - 1.70</td>
</tr>
<tr>
<td>Smoking History (effect of non-smoking)</td>
<td>0.57</td>
<td>0.51 - 0.65</td>
</tr>
<tr>
<td>Boat Manufacturer Status</td>
<td>1.30</td>
<td>0.97 - 1.74</td>
</tr>
</tbody>
</table>

Table 6: Logistic Regression Analysis of FEV1/FVC to Examine the Effect of Predictors on Producing an Abnormal Ratio (<0.80 FEV1/FVC).
Various industries are currently required to use respiratory protection for workers to control inhalation exposures. In order to ensure that workers who are employed in such fields are healthy enough to use respiratory protection, OSHA requires that all such workers undergo periodic pulmonary function testing. The records of this pulmonary function testing may also provide a useful cross section of pulmonary health at the population level for a specific industrial sector, though the data are not currently exploited in this fashion. As well, the presence of the NHANES III spirometry data set provides a robust control population that can be limited to closely reflect the occupational population's salient demographics and adjusted for confounding factors that impact pulmonary function measurements, such as tobacco smoking history.

In the current study, we examined the feasibility of conducting a cross sectional surveillance evaluation of workers in the utility industry from seven utility companies in the state of Florida, which had maintained records of pulmonary function testing for workers required to use respiratory protection. Statistical comparisons between the occupational population and the NHANES III population segment, limited by age and height to reflect the occupational population's demographics, demonstrated the putative factors that altered pulmonary function in our population of interest.

The results of this study indicated that utility workers experienced a modest, but statistically significant, increase in FEV1 and FVC mean values over the NHANES III population in the univariate total population analysis. Stratification by age, height, and smoking history did not indicate statistically significant increases in FEV1 or FVC except in older utility workers.

In the linear regression analysis performed to examine the effect of salient cofactors on pulmonary function, FEV1 analysis demonstrated that age, height, and smoking history all significantly affected pulmonary function of the population in the expected direction. That is to say, increased age and increased pack-years of smoking decreased FEV1, while increased height increased FEV1. Status as a utility worker was also found to have a statistically significant effect on FEV1.

Similar results were reported for the analysis of FVC, with the exception of smoking history, which did not demonstrate statistical significance in this analysis. As well, status as a utility worker conferred a modest, significant increase in FVC. The results of the linear regression analysis for FEV1 and FVC outcomes indicate that the predominant factors that affect pulmonary function values are those traditionally known to impact lung volume and clearance, e.g. age, height, and smoking history. A modest positive effect on FEV1 and FVC was observed for utility workers in both the stratified analysis, as well as the linear regression analysis. This may indicate the presence of the ‘healthy worker effect’ in the occupational population related to more time spent in active labor compared to the NHANES III population which may contain unemployed persons or those engaged in more sedentary labor.

Logistic regression was performed for the outcome of the FEV1/FVC ratio to evaluate the potential for obstructive disorders among the target occupational population compared to the NHANES III population. A cutoff point of less than 0.80 FEV1/FVC was used to classify persons with abnormal FEV1/FVC values that could potentially be an indicator of pre-clinical pulmonary obstruction. In this analysis, status as a utility worker was not significantly associated with an FEV1/FVC value of less than 0.80. However, the analysis clearly demonstrated that the older half as well as the taller half of the population was more likely to produce a lower FEV1/FVC ratio, and non-smokers were less likely to produce a lower FEV1/FVC ratio compared to the smokers in the population.

Through the use of OSHA mandated pulmonary function testing and the available NHANES III spirometry data set, this study was able to efficiently evaluate the pulmonary health of a substantive cross section of a specific industry: utility workers. The data collected in both the OSHA mandated testing and the NHANES III spirometry data allow for the control of confounding factors that impact measures of pulmonary function so that statistical comparisons can identify deficits in pulmonary function and indicate whether or not those deficits are associated with an occupational sector. The current study did not identify any pulmonary function deficits in the target occupational population and it demonstrated that in all cases workers had equivalent or modestly superior pulmonary function compared to a baseline population.

OSHA mandated pulmonary function testing represents a potentially powerful surveillance tool to evaluate at-risk populations who have known inhalation exposures that require respiratory personal protective equipment and regular spirometry evaluations. The principal limitation to conducting this line of research is the current lack of infrastructure to aggregate required pulmonary function testing data. OSHA required that pulmonary function testing be conducted under standard pulmonary function testing guidelines and the resulting data are maintained with employers for compliance purposes. If these data were also transmitted to a local, state, or federal database to be used in population level analysis, the availability and efficacy of this method of surveillance would be greatly enhanced.

References
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