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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 spirograms 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 spirograms were reviewed by a licensed physician and spirograms not meeting American Thoracic Society acceptability and reproducibitlity 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 Students'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 pre-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 $p \leq 0.05$ 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

	Study Population	**NHANES III**
Total Population n =	225	4958
Males n =	225	4958
Females n =	0	0
Smoking History (YES)	93	3144
Smoking History (NO)	132	1814
Median Height (Inches)	70	69
Median Age (Years)	45	41

Table 1: Summary of Study Population and NHANES III Control Population.

Total Population (No Stratification)			
FEV1 (L)			
	Mean	95% CI	p-value
Study Population	**3.81**	3.71 – 3.91	**0.0359**
NHANES III	3.71	3.69 - 3.73	
FVC (L)			
	Mean	95% CI	p-value
Study Population	**4.85**	4.73 – 4.96	**0.0189**
NHANES III	4.70	4.68 - 4.73	

Table 2: Pulmonary Function Means for the Total Population.

Smoking History (YES)			
FEV1 (L)			
	Mean	95% CI	p-value
Study Population	3.65	3.49 - 3.81	0.5815
NHANES III	3.61	3.58 - 3.63	
FVC (L)			
	Mean	95% CI	p-value
Study Population	4.73	4.54 - 4.92	0.3965
NHANES III	4.65	4.62 - 4.68	
Smoking History (NO)			
FEV1 (L)			
	Mean	95% CI	p-value
Study Population	3.93	3.81 - 4.04	0.5304
NHANES III	3.88	3.85 - 3.92	
FVC (L)			
	Mean	95% CI	p-value
Study Population	4.93	4.78 - 5.07	0.0963
NHANES III	4.80	4.76 - 4.84	
Height At Or Above Median (70 inches)			
FEV1 (L)			
	Mean	95% CI	p-value
Study Population	3.99	3.88 - 4.10	0.4511
NHANES III	3.94	3.91 - 3.97	
FVC (L)			
	Mean	95% CI	p-value
Study Population	5.08	4.95 - 5.21	0.5358
NHANES III	5.04	5.00 - 5.07	
Height Below Median (70 inches)			
FEV1 (L)			
	Mean	95% CI	p-value
Study Population	3.43	3.28 - 3.58	0.3402
NHANES III	3.51	3.49 - 3.54	
FVC (L)			
	Mean	95% CI	p-value
Study Population	4.33	4.15 - 4.52	0.3426
NHANES III	4.42	4.39 - 4.45	
Age At Or Above Median (46 years)			
FEV1 (L)			
	Mean	95% CI	p-value
Study Population	**3.63**	3.50 - 3.76	**<0.0001**
NHANES III	3.18	3.15 - 3.22	
FVC (L)			
	Mean	95% CI	p-value
Study Population	**4.65**	4.50 - 4.80	**<0.0001**
NHANES III	4.28	4.24 - 4.32	
Age Below Median (46 years)			
FEV1 (L)			
	Mean	95% CI	p-value
Study Population	4.01	3.88 - 4.15	0.5961
NHANES III	3.98	3.96 - 4.00	
FVC (L)			
	Mean	95% CI	p-value
Study Population	5.06	4.88 - 5.24	0.0848
NHANES III	4.92	4.90 - 4.95	

Table 3: Pulmonary Function Mean Values Stratified by Salient Cofactors.

population. Statistically significant predictors were identified as having a $p \leq 0.05$. The results of the linear regression analysis for FEV1 are reported in table 4. The analysis identified age, height, smoking pack-years, and status as a utility worker as statistically significant predictors of FEV1.

The results of the linear regression analysis for FVC are reported in table 5. The analysis identified age and height, but not smoking history as statistically significant predictors of FVC. The adjusted outcome for status as a utility worker was also a statistically significant predictor of FVC in this analysis.

Logistic regression analysis was used to determine the effect of pulmonary function predictors on generating an FEV1/FVC ratio less than 0.80 (Table 6). From this analysis, three statistically significant factors impacted the FEV1/FVC ratio: age, height, and smoking history. Status as a utility worker was not associated with the production of an FEV1/FVC ratio less than 0.80. Those in the population over the median age (46) and height (71 inches) for utility workers were more likely to produce an FEV1/FVC ratio less than 0.80. Similarly, those with no smoking history were less likely to produce an FEV1/FVC ratio less than 0.80.

Discussion

Part of the strategic plan for the National Institute of Occupational Safety and Health (NIOSH) includes the development and expansion of mechanisms for occupational health surveillance on both the state and federal levels [9]. There is a need to develop and utilize surveillance methodologies that are capable of efficiently evaluating occupational populations for health status, identifying changes in health status over time, and comparing the health status of occupational populations to baseline populations. The use of existing health data to quickly evaluate the health status of a population provides efficiency in both cost and time by limiting the need to perform prospective data collection on a population of interest.

FEV1			
Predictor	**Parameter Estimate**	**Standard Error**	**p-value**
Age at test	**-0.03842**	0.00141	**<0.0001**
Height at test (in)	**0.08397**	0.00486	**<0.0001**
Smoking History (pk-yrs)	**-0.00314**	0.00107	**0.0034**
Utility Worker Status	**0.30053**	0.04526	**<0.0001**

Table 4: Predictors of FEV1 from Linear Regression Analysis.

FVC			
Predictor	**Parameter Estimate**	**Standard Error**	**p-value**
Age at test	**-0.03168**	0.00169	**<0.0001**
Height at test (in)	**0.11685**	0.00583	**<0.0001**
Smoking History (pk-yrs)	0.00199	0.00128	0.1221
Boat Manufacturer Status	**0.24602**	0.05425	**<0.0001**

Table 5: Predictors of FVC from Linear Regression Analysis.

FEV1/FVC <0.80		
Predictor	**Odds ratio**	**95% Confidence Limit**
Age above median >29 years	**3.86**	**3.39 – 4.40**
Height above median >67 inches	**1.48**	**1.30 – 1.70**
Smoking History (effect of non-smoking)	**0.57**	**0.51 – 0.65**
Boat Manufacturer Status	1.30	0.97 – 1.74

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 predominate 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.

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