A Proposed Algorithm for the Identification of Occupational COPD in a Cohort of Washington Workers

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A thesis
submitted in partial fulfillment of the
requirements for the degree of
Master of Public Health

University of Washington
2022

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Program Authorized to Offer Degree:
Occupational and Environmental Medicine

University of Washington

Abstract

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Rationale: Approximately 31% of Chronic Obstructive Pulmonary Disease (COPD) is caused by vapor, gas, dust and fumes (VGDF). In collaboration with the Washington State Department of Labor and Industries Safety and Health Assessment and Research for Prevention Program, we report a new algorithm for surveillance of Occupational COPD. ***Methods:*** Cases were captured from workers' compensation claims filed in Washington state between 2010-2020 using keywords, diagnosis codes (ICD), and occupational injury and illness codes. COPD was confirmed using post-bronchodilator forced-expiratory-volume-over-1-second/forced-vital-capacity (FEV_1/FVC) <0.7 or alternate criteria if spirometry was unavailable. Confirmed claims were evaluated for smoking history, then VGDF exposure was determined using a COPD-specific Job Exposure Matrix based on occupation code. ***Results:*** Of 1,241 initially captured claims, 339 (27.3%) were included in the final analysis. Of these, 94 (27.7%) qualified for Occupational COPD (53 *Probable*, 3 *Possible* and 38 *Work-Aggravated* (*WA COPD*)) while 240 (70.9%) claims were *Not Valid*, including 53 with asthma, and 109 with acute bronchitis. Fifteen total cases that qualified for Occupational COPD were never or <10 pack year smokers, including 13 in the *Probable* group and 2 in the *Work-Aggravated* group. Occupations with expected exposure to medium or high

VGDF included construction workers, firefighters, truck drivers and welders, among others, and there was overlap in occupations and hazards between Occupational COPD groups. *Conclusions:* This comprehensive algorithm provides a framework for Occupational COPD surveillance and diagnosis and could be used to influence resource allocation to improve safety and health in high risk occupations.

Keywords: Chronic Obstructive Pulmonary Disease, COPD, occupation, vapor, gas, dust, fumes, VGDF, exposure, Occupational COPD, worker(s) compensation

Funding: This study was funded in part by the Safety and Health Assessment and Research for Prevention (SHARP) Program at the WA State Department of Labor and Industries and by the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH) Cooperative Agreement; NIOSH grant number: 5U60-OH008487. BR, CW, LK, BD, MC and CS have no financial disclosures or special interests to report. The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Introduction

The burden of Chronic Obstructive Pulmonary Disease (COPD) is increasing worldwide. As of 2019, it was the 3rd leading cause of death globally, accountable for 6% of global deaths[1,2]. In Washington state, 5.7% of adults are estimated to have been diagnosed with COPD[3]. While smoking is the most common, direct cause, the prevalence of smoking is decreasing worldwide[4]. In addition, less than 25% of people who ever smoked ("ever-smokers") are diagnosed with COPD and up to a quarter of those with COPD have never smoked ("never smokers")[5]. As smoking prevalence decreases, work and environmental exposures likely account for an increasing proportion of COPD[6]. Estimates from epidemiologic studies suggest that occupational exposures account for approximately 15% of the total burden of COPD worldwide, and up to 32% of COPD in people who never smoked[4,7,8].

Though cigarette smoke remains the most common respiratory exposure in those with COPD, it is considered a "mixed inhalational exposure," and no specific component has been identified as the etiologic agent of airway obstruction[4]. Occupational exposures to vapor, gas, dust and fumes (VGDF) have been previously linked to increased risk of COPD in both the general population and industry-specific work groups, with studies supporting a causal relationship[7,9-12]. Multiple occupations and individual hazards have been implicated as risks for developing COPD and/or aggravating pre-existing COPD. Occupations previously noted to have elevated rates of COPD include miners, construction workers, welders and agricultural workers, among many others, with exposure to hazards such as respirable silica, coal mine dust, mineral dusts, agricultural dusts, and metal fumes (cadmium and vanadium, e.g.)[9,13-20]. Interestingly, in the United States, office and administrative workers account for a significant burden of cases labeled Occupational COPD among nonsmokers, perhaps due to high exposures to irritant gases and chemicals in the workplace[16,21].

Past studies of occupational COPD have been limited by many factors, making development of consensus diagnostic criteria difficult. First, there is no universally accepted clinical diagnosis of COPD. The Global Initiative for Chronic Obstructive Lung Disease (GOLD)[22-23] and combined American Thoracic Society (ATS)/European Respiratory Society (ERS)[24] guidelines suggest a post-bronchodilator cutoff of forced expiratory volume over 1 second/forced vital capacity (FEV_1/FVC) <0.7 to indicate obstruction. The 1991 ATS guidelines[25] suggest using FEV1/VC (maximal volume of displaced air on any maneuver) rather than a forced vital capacity and a cutoff of the lower limit of normal (LLN), which represent the 5th percentile of the predicted value based on height, sex and ethnicity. More recently, other spirometric parameters have been suggested to be more clinically useful for the diagnosis of obstructive lung disease, especially in symptomatic smokers with normal FEV_1/FVC, including the FEV_1/slow vital capacity (SVC)[26] and forced expiratory volume in 3 s/forced expiratory volume in 6 s (FEV_3/FEV_6)[27]. It is conceivable, therefore, that an individual may qualify for COPD diagnosis by one guideline, while being ruled out for COPD by another. In addition, consistent use of any guidelines for diagnosis and treatment of COPD remains poor in real-world practice, making epidemiological comparison difficult[28].

Second, while occupational exposures are suspected to be contributors to COPD, the dose, duration, and latency of exposure required is unknown. In fact, occupational exposures may be underestimated as contributors to disease in those who smoke. Though smoking and occupational exposures are thought to be at least additive[15,29], experts in respiratory disease and Occupational Medicine mainly attribute COPD to smoking, even in cases of low smoking exposure and high occupational exposure[30]. In addition, COPD typically presents later in life after a long latency period, potentially in the setting of multiple and mixed occupational, environmental or personal exposures[7]. Though the treatment of COPD does not necessarily vary between smoking and occupation-related disease, the appropriate attribution of risk has major implications for the control of VGDF in the workplace, adjudication of workers' compensation claims, distribution of resources for hazard reduction and even policy change.

Third, Occupational COPD does not have a clear case definition. The classification of occupational exposures in population studies ranges from self-reported exposures to semi-quantitative using a Job Exposure Matrix (JEM) (an adaptable list of codified occupations cross-linked to common exposures, used to categorize occupation-specific risk of exposure[31,32]). Many assessments are based on survey data and do not identify a specific exposure, report on duration of exposure, or determine latency between exposure and disease, which increases the chance of misclassification. In addition, occupational exposures are difficult to differentiate from smoking, environmental risk factors, or genetic risk factors for COPD, and the definition of COPD used from study to study varies from self-reported COPD diagnosis to formal diagnosis based on spirometry.

Despite these limitations, Occupational COPD is recognized as a work-related disorder and is a diagnosis of interest among those who manage workers' compensation claims. In Washington State, non-federal employers are required to obtain workers' compensation insurance through the Washington Department of Labor & Industries (WA L&I) unless they meet specific requirements to self-insure or are covered under an acceptable alternative program. L&I's State Fund insurance program provides coverage for 2/3 of workers (approximately 1.9 million) and 99.7% of all employers in the state[33]. Claims data are stored in a centralized data warehouse at L&I and contain the initial report of accident, medical diagnoses, administrative codes, and occupational history.

The health outcomes of occupational respiratory exposures are monitored through L&I's Safety & Health Assessment & Research for Prevention (SHARP) Program[33]. The SHARP respiratory surveillance program tracks claims for work-related asthma (which includes Occupational Asthma, Reactive Airways Dysfunction Syndrome and work-aggravated asthma), occupational COPD, silicosis, asbestos-related lung disease and coccidioidomycosis. The purpose of the surveillance system is to identify clusters of occupational illness that may indicate hazardous exposures and potential sites of intervention. Diseases are passively surveilled using data from claims filed through L&I. Certain conditions already have well-validated surveillance algorithms, such as work-related asthma, which is based on a validated algorithm developed from the National Institute for Occupational Safety and Health (NIOSH) Sentinel Event Notification System for Occupational Risks (SENSOR) program[34].

The main purpose of this study was to develop an algorithm for surveillance of Occupational COPD for the SHARP program. Using this algorithm, we evaluated a cohort of Washington workers who filed claims for respiratory conditions to determine the prevalence of Occupational COPD in this population.

Abbreviations

AOEC	Association of Occupational and Environmental Clinics	*NCHS*	National Center for Health Statistics
ATS	American Thoracic Society	*NHANES*	National Health and Nutritional Examination Survey
CDC	Centers for Disease Control and Prevention	*NIOSH*	National Institute for Occupational Safety and Health
COPD	Chronic Obstructive Pulmonary Disease	*NOS*	Not otherwise specified
ERS	European Respiratory Society	*OIICS*	Occupational Injury and Illness Classification System
FEV_1	Forced Expiratory Volume over 1 Second	*SENSOR*	Sentinel Event Notification System for Occupational Risks
FVC	Forced Vital Capacity	*SHARP*	Safety & Health Assessment & Research for Prevention
GOLD	Global Initiative for Chronic Obstructive Lung Disease	*SOC*	Standard Occupational Classification Codes 2000
ICD	International Classification of Diseases	*SVC*	Slow Vital Capacity
JEM	Job Exposure Matrix	*USCB*	U.S. Census Bureau Occupation Codes 2002
L&I	Washington State Department of Labor and Industries	*VGDF*	Vapor, Gas, Dust or Fumes
MESA	Multi-Ethnic Study of Atherosclerosis Lung Study	*WA*	Work Aggravated
NAICS	North American Industry Classification System		

Methods:

Study design:

In this study, we used workers' compensation insurance claim data from an administrative database for a cohort of Washington workers to develop a surveillance algorithm and conceptual framework for the diagnosis of Occupational COPD. We performed a descriptive analysis of the included claims to determine prevalence of Occupational COPD in this population and associated occupations and hazards.

All surveillance protocols and data handling were approved by the Washington State Institutional Review Board (WSIRB).

Patient Population:

The primary data source for this study was workers' compensation claims, submitted to Washington State Labor and Industries (L&I) between 2010 and 2020. Claims were included regardless of claim status (e.g. accepted, rejected, open, closed, etc) after a grace period of at least one year maturation to ensure appropriate time for diagnostic workup to take place. Potential COPD cases were captured from the L&I industrial insurance data warehouse using specific "case capture criteria," including keywords (allowing for common misspellings), ICD9-CM and ICD10-CM codes (International Classification of Diseases, 9th and 10th edition, Clinical Modification[35]), and Occupational Injury and Illness Classification System (OIICS) codes[36] **(Case Capture Criteria, Table 1).** OIICS codes are assigned by a team of at least three reviewers at L&I within two weeks of claim submission and are classified as either "accident codes" (e.g. inhalation of substance) or "nature codes" (e.g. Chronic Obstructive Pulmonary Disease). ICD codes were captured from initial Report of Accident forms, medical or hospital billing records, or "allowed" diagnosis codes (diagnoses accepted by L&I for each claim). Each claim potentially included multiple ICD codes. Claims that did not meet case capture criteria were excluded. In this manuscript, "claims" and "cases" will be used interchangeably to refer to individuals included.

All claims for adults ≥18 years old that met case capture criteria as defined above (n=1,241) were individually evaluated for appropriateness. Claims were excluded if they were filed for non-respiratory conditions (n=12) or Sars-CoV-2 infection (n=25), or were outside the study cohort years (claims with injuries occurring in 2020 but filed in 2021, n=21).

Table 1: Case Capture Criteria	
Cases included if they meet ANY of the following	
Keywords (allows for misspellings)	
COPD	
Bronchitis	
Emphysema	
OR	
OIICS code	**Code Description**
340 (accident)	Exposure to caustic, noxious, or allergenic substances, unspecified
341 (accident)	Inhalation of substance
1440 (nature)	Chronic Obstructive Pulmonary Disease
1449 (nature)	Bronchiectasis
OR	
ICD 10	**Code Description (includes subcodes)**
J40	Bronchitis not specified as acute or chronic
J41	Simple and mucopurulent Chronic Bronchitis
J42	Unspecified Chronic Bronchitis
J43	Emphysema
J44	Other Chronic Obstructive Pulmonary Disease
ICD 9	**Code Description (includes subcodes)**
490	Bronchitis not specified as acute or chronic
491	Chronic Bronchitis
492	Emphysema
496	Chronic Airway Obstruction NEC
COPD = Chronic Obstructive Pulmonary Disease; OIICS = Occupational Injury and Illness Classification System codes; ICD = International Classification of Diseases	

In an iterative process, descriptive analyses were performed for the first 100 captured claims to determine further inclusion criteria and develop a working algorithm for Occupational COPD. Through this iterative process, we determined only claims that contained COPD ICD codes should progress to the diagnostic pathway. However, to minimize inclusion of non-respiratory cases that coincidentally contain a COPD ICD code, and to account for limitations of the data storage, the case capture criteria are applied prior to further screen by ICD code.

Of the initial 1,241 captured claims, 523 claims met ICD code criteria (n = 660 excluded). Individual medical notes and work history for each claim that met case capture criteria were analyzed by two reviewers. Due to the number of claims and volume of records present in each claim, for feasibility we report data from claims filed between 2010-2012 and 2016-2020 (n= 339 claims). The remaining claims will be reviewed at a later date. The analysis profile is presented in **Figure 1**.

Figure 1: Analysis profile

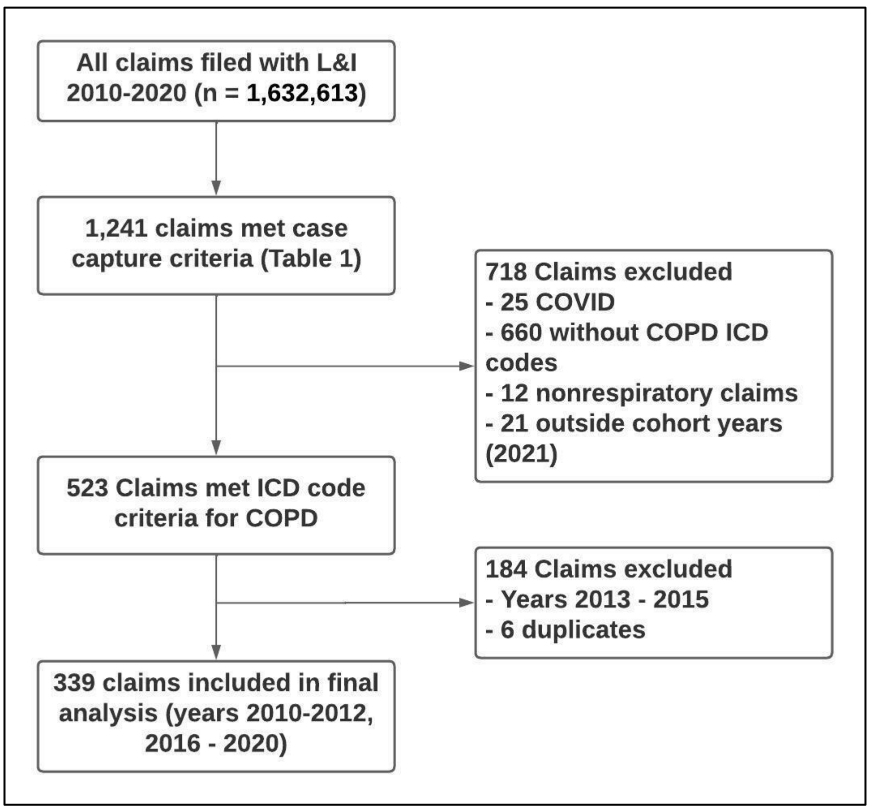


Figure 1: Profile of claim inclusion with reasons for exclusion. Claims were included if they met case capture criteria. Due to feasibility, only claims filed between 2010-2012 and 2016-2020 were included in the final analysis. L&I = Labor and Industries, COVID = coronovirus disease of 2019, COPD = Chronic Obstructive pulmonary Disease, ICD = International Classification of Diseases

Confirmation of COPD diagnosis:

All claims included in the final analysis were initially evaluated for accuracy of COPD diagnosis. For each case, diagnosis was confirmed using GOLD criteria of post-bronchodilator FEV_1/FVC <0.7 or alternate criteria if spirometry was not available (**Table 2**)[13,22-23,33,37]. For certain cases, only pre-bronchodilator spirometry was available. These cases were required to have both pre-bronchodilator FEV_1/FVC <0.7 PLUS physician diagnosis of COPD to be considered a potential Occupational COPD case to avoid misclassification of asthma.

Table 2: Alternate Diagnostic Criteria for COPD Diagnosis
1. Physician diagnosis of COPD AND classic symptoms (cough, dyspnea, wheeze, bronchitis, or exacerbations)
OR
2. Statement by a specialist that Spirometry is consistent with COPD
OR
3. Imaging reports consistent with emphysema
OR
4. Physician statement of history of COPD preceding claim

Assessment of Smoking and Exposure history:

Smoking history assessment:

Smoking history was determined through direct review of available medical notes and calculated as pack-years (number of packs per day multiplied by total number of years smoked).

Attribution of smoking duration to disease:

Smokers were classified using definitions from the Centers for Disease Control and Prevention: National Center for Health Statistics (CDC NCHS)[38]. A smoker is someone who has smoked at least 100 cigarettes in a lifetime. Current smokers include people who smoke every day or some days, while former smokers are those who have quit at the time of initial evaluation. Never smokers are those who have smoked <100 cigarettes in a lifetime. Claimants in our cohort were categorized as former smokers if documentation suggested they had fully quit smoking by the time of claim filing. If smoking history varied across documentation, the highest number of pack years was chosen. Accurate assessment of timing of smoking relative to an individual's workplace exposures could not be performed with the available data.

For attribution of smoking risk, cases were divided into two groups: Those with 0-10 pack-year history (including never smokers) and ever smokers (current or former) with ≥10 pack-year history. While the risk of lung disease increases after 100 lifetime cigarettes, a cutoff of ≥10-15 pack-years has historically been the minimum required to develop COPD[7,39-40]. As the purpose of this study was Occupational COPD surveillance, a ten year cutoff was chosen to ensure appropriate capture of cases.

Claims were stratified by smoking status (binary cutoff of <10 pack years vs. ≥10 pack years) then assessed for duration of exposure to VGDF as documented below and in **Figure 2**.

***Occupational Exposure Assessment*:**

The lifetime work history for each claimant was determined through direct review of Report of Accident forms, available medical notes, work history forms and employer-provided documents, if available. Occupations were coded using 2002 U.S. Census Bureau Occupation Codes (USCB)[31] codes cross-referenced with 2000 Standard Occupational Classification (SOC) codes[41] to assign a JEM risk category. The industry of the claimant's employer was coded using North American Industry Classification System (NAICS) codes[42]. The JEM used for this study was originally designed from the European Community Respiratory Health Survey to assess occupational asthma,[43] then later adapted to assess COPD[20]. It was adapted by NIOSH and validated using large-scale population data from both the National Health and Nutritional Examination Survey (NHANES) database and the Multi-Ethnic Study of Atherosclerosis (MESA) Lung Study[1-2,6,16-19].

This validated JEM is currently used by SHARP to assign a semi-quantitative risk category to individual occupations based on the likelihood of exposure to VGDF. In contrast to JEMs used previously for asthma, the COPD-specific JEM categorizes dusty trades as moderate to high risk, while occupations with likely exposure to immune sensitizers were considered lower risk[39]. JEM1, JEM2 and JEM3 represent low, medium, and high expected VGDF exposure, respectively. Up to five individual exposures reported by each claimant were coded using Association of Occupational and Environmental Clinics (AOEC) codes[44].

Both duration spent in the job of injury and total career duration in a JEM2 or JEM3 job were recorded. For this analysis, only career duration in a JEM2 or JEM3 job was used to more closely represent total risk. If career work history was not available, the job of injury was used for total career duration if consistent with JEM2 or JEM3 exposure. Claims with JEM1-associated exposures in the job of injury and no other work history reported were classified as having zero total high risk career exposure.

Attribution of Occupational Exposure duration to disease:

A total career duration of ≥ 5 years in a JEM2 or JEM3 occupation was considered the minimum "dose" and duration required for development of Occupational COPD. This cutoff represents the lower limit of "plausible" exposure duration required to cause COPD and was determined based on historical dose-response studies, including longitudinal cohort studies in specific industries, and expert opinion on apportionment for Occupational COPD due to VGDF exposure[8,30,45-46].

Algorithm for the Classification Occupational COPD:

Figure 2 represents the final surveillance and diagnostic algorithm for disposition of claims and determination of Occupational COPD. Cases with confirmed COPD were stratified by smoking history (<10 pack years vs. ≥ 10 pack years) then further stratified by total career duration in an occupation associated with medium or high VGDF (JEM2 or JEM3, respectively).

Cases were classified as *Probable Occupational COPD* if they met the following criteria:

1. 0-10 smoking pack years AND ≥5 years *high* VGDF (JEM3) OR ≥10 years *medium* VGDF (JEM2) exposure

   OR

2. ≥10 smoking pack years AND ≥10 years *high* VGDF (JEM3) OR ≥20 years *medium* VGDF (JEM2) exposure

Cases were classified as *Possible Occupational COPD* if they met the following criteria:

1. ≥10 smoking pack years AND ≥5 years but <10 years *high* VGDF (JEM3) OR ≥10 but <20 years *medium* VGDF (JEM2) exposure

In contrast, cases with COPD preceding exposure were considered *Work Aggravated* COPD (*WA COPD*) if they had documentation of ANY acute or chronic exposure to ANY VGDF, regardless of JEM risk category. Exceptions included non-VGDF hazards, such as viral or bacterial infectious exposures, which were classified as *Not Valid*.

Cases were classified as *Not Valid* if they did not meet criteria for COPD diagnosis, or at least 5 years of exposure to *high* VGDF or 10 years exposure to *medium* VGDF. Cases that did not have enough information on diagnosis or VGDF were considered *Undetermined.*

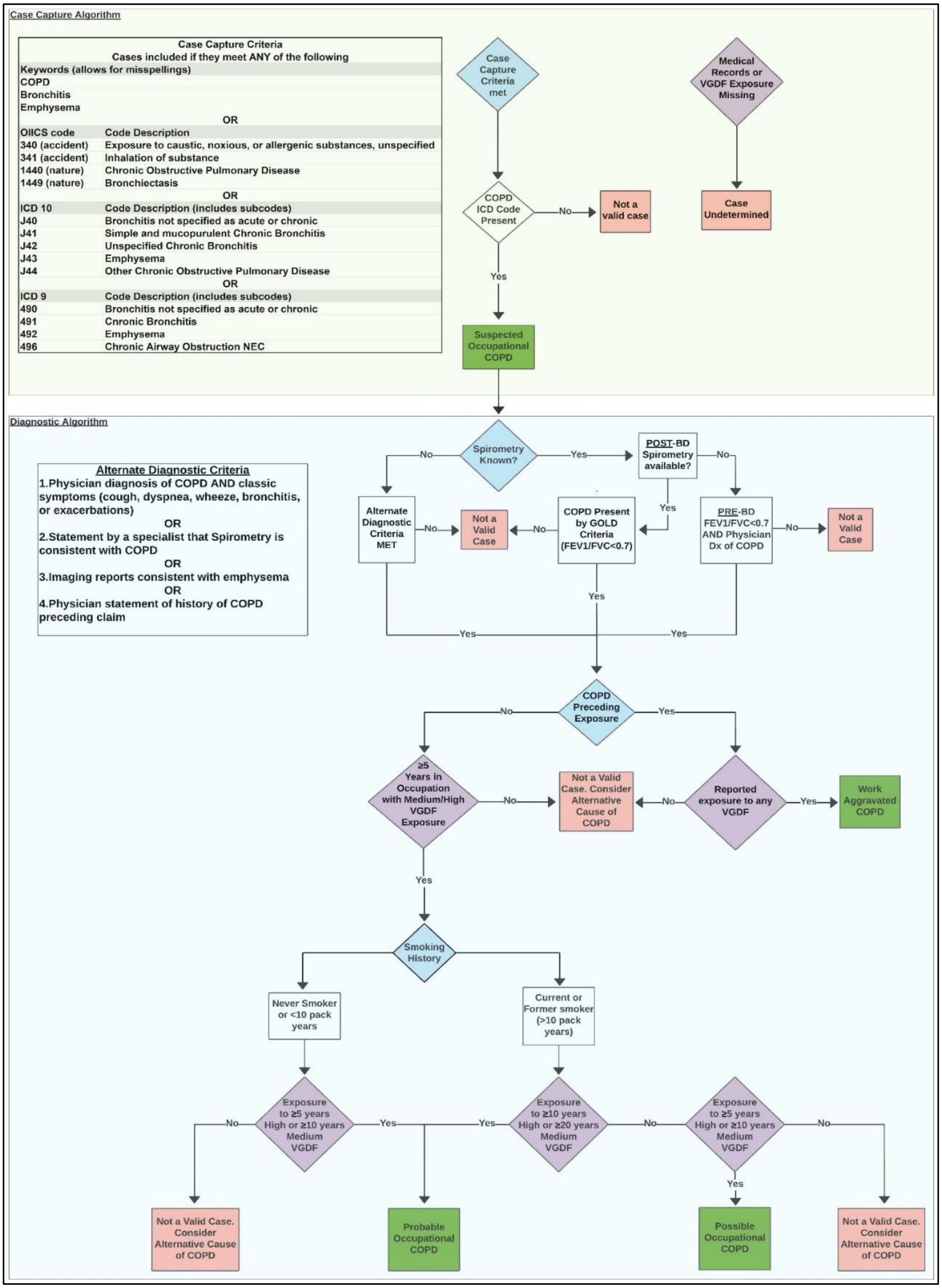
Descriptive Analysis:

Descriptive analysis was performed and reported for cases that met criteria for Occupational COPD. Most *Not Valid* cases were designated early in the evaluation process and therefore may not contain complete information for analysis.

The exceptions are age, sex, occupation and exposure history, which were gathered for all claims if available. Missing data are described below.

Figure 2: Surveillance and Diagnostic Algorithm for Occupational COPD

Green boxes represent "Occupational COPD" for surveillance purposes at SHARP.



Comparative Analysis:

A two-sample t-test at the 0.05 level was performed to compare mean age between Occupational COPD cases and *Not Valid* cases. Because the distribution of values in the two groups did not follow a normal distribution, confirmatory nonparametric testing was also performed using the Mann Whitney U test (Wilcoxon Rank Sum Test). Significance did not change by analysis, and only the results of the t test are reported here.

A two sample test of proportions was used to determine differences in proportion of males between the various groups.

Initially, a control group from the general population using NHANES data was planned for a case to case comparison study. However, there were irreconcilable differences between the two databases, including substantially different definitions for COPD diagnosis, smoking history, and VGDF exposure for the years of interest, limiting meaningful comparison between the databases. Assessment of the utility of self-reported diagnosis and exposures compared to measured values is beyond the scope of this paper.

All calculations were done using R version 4.1.1 and Excel 2016.

Results:

Figure 3 shows the total number claims filed with WA L&I for any injury or disease plotted by year. These include data from years 2013-2015, which are not available for the rest of the analyses as described above.

Figure 3: Total Number of Claims Filed with WA L&I by Year

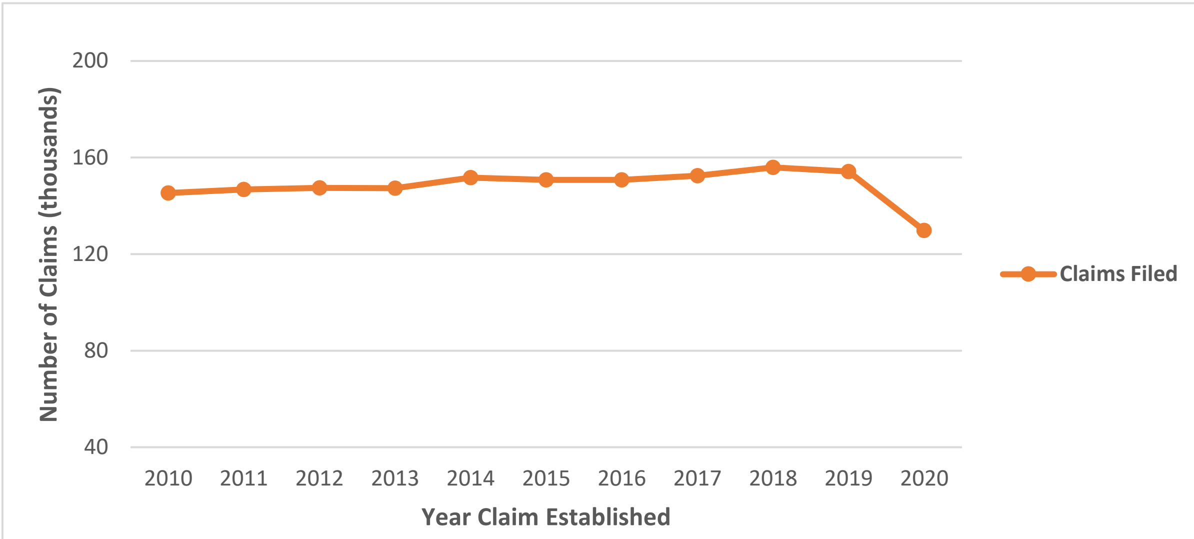
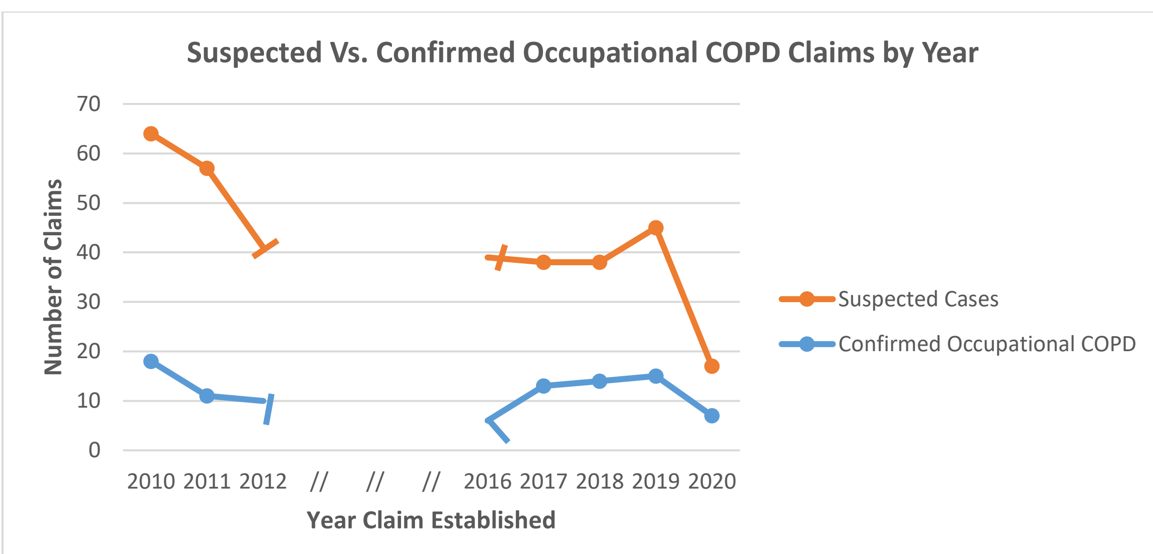


Figure 4 represents the number of confirmed Occupational COPD cases compared to the number of suspected Occupational COPD cases (all claims that met case capture criteria), plotted by year of claim establishment. Data from years 2013-2015 are not reported and are marked with a stop line on the graph above.

Figure 4: Suspected vs. Confirmed Occupational COPD Cases by Year



Of the 1,241 claims that met case capture criteria, 523 claims met ICD code criteria for inclusion (42.1%).

We conducted a pilot study with 100 cases to develop the algorithm seen in **Figure 2**. Of these claims, 20% were filed specifically for COPD on the initial Report of Accident form, while 56% had COPD-specific ICD codes within their medical record. Of those with COPD-specific ICD codes, only 39% (total 22 claims) had COPD confirmed by either GOLD criteria or alternate criteria. For these 22 cases, the mean age at filing was 55.2 years ± 8.53 years. 85% were ever-smokers with a median 30 pack year history (IQR 24 pack years). The mean FEV1 was 1.75L ± 0.60L and the mean career exposure to medium/high VGDF was 21.3 years ± 15.34 years. We then applied the algorithm to these cases and 18 ultimately met criteria for *Probable, Possible,* or *WA* Occupational COPD. The four excluded cases met criteria for COPD but did not meet criteria for occupational exposures. We then applied the algorithm to the full cohort.

The data reported here include data from years 2010-2012 and 2016-2020 due to feasibility (n = 339) as described above. The results of the descriptive analysis are reported in **Table 3**, stratified by Occupational COPD group. Select data for the *Not Valid* group is reported below and no data are available for the *Undetermined* group by definition.

Of the 339 suspected Occupational COPD cases, 94 (27.7%) qualified for Occupational COPD based on our algorithm: 53 were designated as *Probable* (15.6% of total suspected), 3 as *Possible* (0.9%), and 38 as *WA COPD* (11.2%). 240 cases (70.9%) were *Not Valid* and 5 (1.5%) were *Undetermined*. Of the 240 *Not Valid* cases, 53 (22%) were classified as having asthma and 109 (45%) were classified as having acute bronchitis.

FEV_1/FVC data were missing for 2 (66.7%) *Possible* cases, 15 (28.3%) *Probable* cases, and 30 (78.9%) *WA COPD* cases with diagnosis confirmed using alternate criteria. The total career duration of exposure was missing, with the job of injury duration of exposure used as a surrogate, in 186 (54.9%) total cases, including 1 (33.3%) *Possible* case, 10 (18.9%) *Probable* cases, and 25 (65.8%) *WA COPD* cases. The majority of missing data occurred in the *Not Valid* and *Undetermined* cases. The majority of *Probable* cases with only the job of injury exposure data available worked most or all of their career in a single position so that total career duration of exposure and job of injury duration of exposure were the same. In contrast, most of those with missing data in the *WA COPD* and *Not Valid* cases had no work history documented beyond the job of injury.

There were significant differences in the baseline characteristics between those with Occupational COPD and cases classified as *Not Valid*. Those with *Probable* Occupational COPD were significantly older than those in the *Not Valid* group by 17.2 years [95% CI (14.0, 20.4), p <0.0001] and were 6.2 years older than the *WA COPD* group [95% CI (2.22, 9.72), p = 0.002]. Those with *Possible* Occupational COPD were significantly older than those in the *Not Valid* group by 13 years [95% CI (8.6, 17.4), p = 0.001] while those with *WA COPD* were significantly older than the *Not Valid* group by 11.2 years [95% CI (8.1, 14.4), p<0.0001). There was no significant difference in age between the *Possible* group and either the *Probable* or *WA COPD* groups.

The proportion of males was significantly higher in the *Probable* group vs the *Not Valid* group [Δ0.32, 95% CI (0.22, 0.42), p<0.0001) and vs. the *WA COPD* group [Δ0.34, 95% CI [0.15, 0.53], p<0.001). The proportion of males in the *Probable* group was not significantly different from the

Possible group. There was no significant difference between the proportion of males in the *Not Valid* group and the *Possible* and *WA COPD* groups.

The mean career duration of exposure to medium and/or high VGDF was 6.3 ± 9.6 years (median 2, IQR =7.8) for the *Not Valid* group, 29.5 ± 9.1 years (median 30, IQR 12) for the *Probable* group, 13.41 ± 3.4 years (median 13, IQR 3.4) for the *Possible* group, 6.3 ± 8.2 years (median 2.5, IQR 9.5) for the *WA COPD* group and 19.3 ± 14.2 years (median 19.0, IQR 26.1) for all Occupational COPD groups combined.

A total of 15 claimants with confirmed Occupational COPD either never smoked or smoked <10 pack years, including 13 *Probable* cases (n=6 never smoked) and 2 *WA COPD* cases, both of whom smoked <10 pack years. All *Possible* cases had smoked for ≥10 years. Pack year history was missing for 12 *WA COPD* cases and 1 *Probable* case. This *Probable* case had >20 years exposure to a JEM2 occupation, resulting in disposition as *Probable* Occupational COPD regardless of smoking status.

Since smoking history and the duration of time spent in a JEM2 or JEM3 job with medium/high expected exposure to VGDF determined disposition, comparative analysis between groups for these variables would not be valid and are therefore not reported.

Table 3: Descriptive Analysis of Final Claims				
Variable	**Total (N = 339)**	**Probable Occupational COPD (N = 53)**	**Possible Occupational COPD (N = 3)**	**Work Aggravated Occupational COPD (N = 38)**
Age [years] (M±SD)	50.5 (14.2)	63.5 (9.8)	59.3 (2.3)	57.5 (8.0)
N (%) Male	228 (67.3%)	50 (96%)	2 (67%)	23 (61%)
Spirometry				
FEV1/FVC (M±SD)	0.69 (0.14)	0.57 (0.10)	0.52 (NA)	0.52 (0.07)
FEV1 [L] (M±SD)	2.55 (0.90)	2.05 (0.64)	1.30 (NA)	1.82 (0.56)
Mean FEV1 % Pred (SD)	72.0% (19.9%)	60.4% (17.8%)	NA	52.2% (7.9%)
FVC [L] (M±SD)	3.65 (1.03)	3.66 (0.88)	2.52 (NA)	3.48 (0.98)
Mean FVC % Pred (SD)	83.3% (17.7%)	82.5% (18.2%)	NA	82.3% (13.2%)
Mean DLCO (M±SD)	23.9 (13.6)	21.2 (9.7)	NA	18.9(6.6)
Mean DLCO % Pred (SD)	70.7% (25.1%)	61.8% (26.9%)	NA	55.6% (10.6%)
FEV1/FVC Ratio data missing [n(%)]	***208 (61.4%)***	***15 (28.3%)***	***2 (66.7%)***	***30 (78.9%)***
Smoking Status [n (%)]				
Never Smoker (<10 years)	69 (20.4%)	13 (24.5%)	0 (0%)	2 (5.3%)
Current or Former Smoker (≥10 years)	97 (28.6%)	39 (73.6%)	3 (100%)	24 (63.2%)
Smoking Pack Years [Median (IQR)]	15 (30)	20 (31)	30 (14.5)	30.0 (23.5)
Smoking Status or Pack Years Data Missing	173 (51.0%)	1 (1.2%)*	0 (0%)	12 (31.6%)
Median Career Exposure to Med and/or High VGDF [years (IQR)]	3 (17.75)	30 (12.0)	13 (3.4)	2.5 (9.5)
Job of Injury used as surrogate for Missing Career Exposure Duration	***186 (54.9%)***	***10 (18.9%)***	***1 (33.3%)***	***25 (65.8%)***

In the *Not Valid* group, mean age of claimants was 46.3 ± 13.6 years, median career duration of VGDF exposure was 2.0 years (IQR 8.0; mean 6.3 ± 9.6) and the proportion of males was 0.62. *Current smoker, pack years missing. Career duration in JEM2 occupation was 20 years, which would qualify for Probable COPD regardless of smoking history. NA = Data Not Available for that variable.

The industries, occupations, and reported exposures for the different Occupational COPD groups are listed in **Table 4**. Claimants with *Probable* and *Possible* Occupational COPD by definition were found only in JEM2 and JEM3 occupations. The most common occupations in the *Probable* group included welders/brazers/solderers, general production workers, truck drivers, and construction workers/painters and the top five most commonly reported exposures in this group were unspecified dust, crystalline silica, welding fumes, metal dust/fumes, and diesel fuel/exhaust. Asbestos and diesel fuel/exhaust were the most commonly reported exposures in the *Possible* group, which included drivers and production workers. In the *WA COPD* group, janitors and building cleaners were the most commonly reported occupation with frequently reported exposure to cleaning materials (including bleach and other disinfectants, carpet cleaner, oven cleaner, drain cleaner and floor stripper), general unspecified dust, and mold.

Table 4: Industries, Occupations and Exposures by Occupational COPD Group

Disposition Group (n = 339)	Industry	USCB Occupations	Commonly Reported Exposures
Probable Occ COPD [n=53 (15.6%)]	Manufacturing (n=9) Construction (n=6) Agriculture, Forestry, Fishing and Hunting (n=2) Mining, Quarrying, and Oil and Gas Extraction (n=2) Wholesale trade (n=2) Retail Trade (n=2) Administrative and Support and Waste Management and Remediation Services (n=2) Educational Services (n = 2) Public Administration (n =2) Utilities (n=1) Unknown/Unclassifiable (n=20)	**JEM2** Production Workers, All Other (n=6) Driver/Sales Workers and Truck Drivers (n=3) Automotive Service Technicians and Mechanics (n=1) Civil Engineers (n=1) Construction and Building Inspectors (n=1) First-Line Supervisors/Managers of Production and Operating Workers (n=1) Food Preparation Workers (n=1) Industrial Truck and Tractor Operators (n=1)	Dust, NOS (n=16) Crystalline Silica (n=12) Welding Fumes (n=11) Metal Fumes or Dust (n=10) Diesel fuel/exhaust (n=10) Paint [n=6 (epoxy, oil-based, NOS)] Solvents NOS (n=5) Smoke [n=5 (roof tar fumes, NOS)] Wood Dust NOS (n=3) Fiberglass (n=3) Drywall Mud (n=2) Diatomaceous earth [aka amorphous silica (n=1)] Cerium Compounds (n=1) Copper (n=1) Sulfur Dioxide (n=1) Freon (n=1)

		Laborers and Freight, Stock, and Material Movers, Hand (n=1) Maintenance and Repair Workers, General (n=1) Other Installation, Maintenance, and Repair Workers (n=1) Printing Machine Operators (n=1) Shoe and Leather Workers and Repairers (n=1) **JEM3** Welding, Soldering and Brazing Workers (n=5) Painters, Construction and Maintenance (n=3) Roofers (n=2) Bus and Truck Mechanics and Diesel Engine Specialists (n=2) Carpenters (n=2) Firefighters (n=2) First-Line Supervisors/Managers of Construction Trades and Extraction Workers (n=2) Bakers (n=1) Cabinetmakers and Bench Carpenters (n=1) Farm, Ranch, and Other Agricultural Managers (n=1) Farmers and Ranchers (n=1) Grinding, Lapping, Polishing, and Buffing Machine Tool Setters, Operators and Tenders, Metal and Plastic (n=1) Grounds Maintenance Workers (n=1) Hairdressers, Hairstylists, and Cosmetologists (n=1) Insulation Workers (n=1) Logging Workers (n=1) Millwrights (n=1) Miscellaneous Construction and Related Workers (n=1) Molders and Molding Machine Setters, Operators, and Tenders, Metal and	Hair Products (n=1) Fumes NOS (n=1) Organic Dust (n=1) Flour (n=1) Western Red Cedar (n=1)

		Plastic (n=1) Operating Engineers and Other Construction Equipment Operators (n=1) Painting Workers (n=1) Structural metal Fabricators and Fitters (n=1)	
Possible Occ COPD [n=3 (0.9%)]	Manufacturing (n=1) Transportation and Warehousing (n=2) Other services (n=1)	**<u>JEM2</u>** Driver/Sales Workers and Truck Drivers (n=2) Industrial Truck and Tractor Operators (n=1) Production Workers, All Other (n=1)	Asbestos NOS (n=2) Diesel fuel/exhaust (n=3) Wood Dust NOS (n=1) Ammonium Hydroxide (n=1) Dust NOS (n=1) Ethylene Glycol (n=1) Chemicals NOS (n=1)
Work Aggravated COPD [n=38 (11.2%)]	Health Care and Social Assistance (n=6) Manufacturing (n=6) Accommodation and Food Services (n=4) Other Services (n=4) Retail Trade (n=4) Construction (n = 3) Wholesale Trade (n=3) Administrative and Support and Waste Management and Remediation Services (n=2) Transportation and Warehousing (n = 2) Real Estate and Rental and Leasing (n = 1) Educational Services (n = 1) Public Administration (n = 1) Agriculture, Forestry, Fishing and Hunting (n = 1)	**<u>JEM1</u>** Cashiers (n=1) Electricians (n=1) Medical and Health Service Managers (n=1) Medical Assistants and Other Healthcare Support Occupations (n=1) Nursing, Psychiatric, and Home Health Aides (n=1) Receptionists and Information Clerks (n=1) Retail Salespersons (n=1) Social Workers (n=1) Transportation, Storage, and Distribution Managers (n=1) **<u>JEM2</u>** Cooks (n=2) Driver/Sales Workers and Truck Drivers (n=2) Inspectors, Testers, Sorters, Samplers, and Weighers (n=2) Aircraft Structure, Surfaces, Rigging and Systems Assemblers (n=1) Bartenders (n=1) Butchers and Other Meat, Poultry, and Fish Processing Workers (n=1) Cleaners of Vehicles and Equipment (n=1) First-Line Supervisors/Managers of Mechanics, Installers, and Repairers (n=1) Food Preparation and Serving	Cleaning Materials [n= 9 (sodium hypochlorite, carpet cleaner, disinfectant, oven cleaner, floor strippers, drain cleaner, NOS)] Dust NOS (n=6) Mold NOS (n=4) Chemicals NOS (n=3) Chlorine (n=2) Carbon Monoxide (n=2) Diesel Exhaust (n=2) Smoke NOS (n=2) Wood Dust NOS (n=2) Fly Ash (n=1) Fiberglass (n=1) Crystalline Silica (n=1) Metal Fumes NOS (n=1) Hydrochloric Acid (n=1) Solvents NOS (n=1) Paint NOS (n=1) Isocyanates (n=1) Monoethanolamine (n=1) Lubricants (n=1) Indoor Air Pollutants From Building Renovation (n=1) Ammonium Hydroxide (n=1) Western Red Cedar (n=1) Crabs (Pleocyemata suborder) (n=1) Adhesive Glue NOS (n=1) Butyl Acetate (n=1) Diethylene Glycol (n=1) Degreaser NOS (n=1) Methyl Propyl Ketone (n=1) Methyl Ethyl Ketone (n=1) Epoxy resins (n=1) Isophorone (n=1) Ethyl Acetate (n=1)

		Related Workers, All Other (n=1) Industrial Truck and Tractor Operators (n=1) Other Installation, Maintenance, and Repair Workers (n=1) Production Workers, All Other (n=1) **JEM3** Janitors and Building Cleaners (n=5) Miscellaneous Construction and Related Workers (n=2) Automotive Body and Related Repairers (n=1) Bakers (n=1) Cabinetmakers and Bench Carpenters (n=1) Laundry and Dry-Cleaning Workers (n=1) Packers and Packagers, Hand (n=1) Service Station Attendants (n=1) Welding, Soldering, and Brazing Workers (n=1)	

The industries, occupations and exposures for those who never smoked or smoked <10 pack years are listed in **Table 5**. Only those in the *Probable* and *WA COPD* groups are included as all three claimants in the *Possible* group were considered ever smokers with ≥10 pack years.

Table 5: Occupation and Exposures in Occupational COPD Cases with <10 Pack Year Smoking History		
Disposition Group	**USCB Occupation**	**Common Exposures**
Probable Occupational COPD (n=13)	Operating Engineers and Other Construction Equipment Operators (n=1)	Diesel exhaust/fuel; Cement Dust; Asbestos, NOS; Smoke, NOS
	Painters, Construction and Maintenance (n=2)	Crystalline Silica, NOS; Asbestos, NOS; Zinc Compounds; Paint, Epoxy; Dust, NOS; Paint, NOS; Drywall Mud
	Welding, Soldering, and Brazing Workers (n=3)	Metal Dust, NOS; Dust, NOS; Cutting Oils (metalworking fluids)
	Industrial Truck and Tractor Operators (n=1)	Crystalline Silica, NOS
	Millwrights (n=1)	Copper; Paper Dust; Asbestos; Metal Dust, NOS
	Logging Workers (n=1)	Crystalline Silica, NOS; Ash, NOS
	Grounds Maintenance Workers (n=1)	Diesel fuel; Welding fume, NOS; Heavy metals, NOS
	Firefighters (n=1)	Smoke, NOS; Dust, NOS
	Production Workers, All Other (n=2)	Wood Dust, NOS; Quartz Dust; Fiberglass; Glues; NOS; Welding Fume, NOS; Crystalline Silica, NOS; Rock, NOS; Metal Dust; NOS; Asphalt
WA Occupational COPD (n=2)	Food Preparation and Serving Related Workers, All Other (n=1)	Oven Cleaners
	Production Workers, All Other (n=1)	Paint, NOS; Dust, NOS

Discussion:

Occupational exposures are major, but under-recognized, contributors to the global burden of COPD. To date, there is no universally accepted definition of Occupational COPD, which makes individual diagnosis difficult and limits the ability of health and safety experts to reduce workplace risks. In the world of workers' compensation, accurate diagnosis, robust surveillance and appropriate attribution of risk may have major implications for receipt of appropriate healthcare resources, time loss compensation and even health and public policy [47].

In this study, we present a comprehensive and adaptable algorithm for the surveillance and diagnosis of Occupational COPD. This algorithm was developed using worker's compensation data from the WA L&I industrial insurance data warehouse for the purpose of identifying occupations and exposures that may increase the risk of COPD. Though there is no universally accepted causative level for either smoking or for workplace exposure to VGDF, in our algorithm we chose the most "plausible" lower limits consistently reported in the literature and based on expert opinion, to allow for appropriate identification of cases for surveillance purposes[8,30,45-46]. This algorithm will be adopted by the WA L&I SHARP Occupational Respiratory Disease Surveillance System[33] with the goal of directing state resources to identify and reduce exposures in high risk occupations in Washington state. As such, it has the potential to help identify causes of COPD due to industrial processes that were previously unknown.

We applied our algorithm to a cohort of Washington workers who submitted respiratory claims to WA L&I over a ten year period. In this descriptive study, we report the industries, occupations and common exposures identified for cases that met our proposed criteria for Occupational COPD. As expected, occupations associated with dusty exposures (respirable silica, welding fumes, metal dust/fumes, diesel, and construction dust, etc.) were more commonly seen in those designated as *Probable* Occupational COPD, while irritant exposures, especially cleaning chemicals, were more commonly seen in the *WA COPD* group. However, there was overlap in occupations and exposures between the groups.

In our population, cases that met criteria for Occupational COPD differed significantly from those designated as *Not Valid*. Those with Occupational COPD (all groups) were older than those in the *Not Valid* group, while those with *Probable* Occupational COPD were more likely to be male than cases designated *Not Valid* or *Work Aggravated*. This is consistent with previous evidence that suggests COPD is more common in those ≥40 years old and less common in women, with historical female prevalence around 5.6%[49,50-52]. The proportion of women who qualified for *Probable* Occupational COPD was consistent with these findings, while the proportion of women was higher than expected in the WA group. Women have genetic and hormonal differences that affect long term lung health and may have differing workplace and environmental exposures than men [53]. In recent years, COPD has increased in prevalence in the female population and women represent the vast majority of nonsmokers with COPD [54]. In addition, misdiagnosis, delayed diagnosis, and severe outcomes occur more frequently in women [55]. Our findings suggest that women remain a particularly vulnerable population and may warrant closer attention going forward. Interestingly, however, the small number of nonsmokers in our population was mostly in male claimants.

It is not surprising that so few cases ultimately met criteria for Occupational COPD. This is likely due to multiple reasons. These data represent only those who file claims for respiratory symptoms and likely under-represent the true burden of Occupational COPD in the general working population. Providers and workers may not recognize the contribution of workplace VGDF exposures, especially in those with a heavy smoking history, and therefore may never file claims for Occupational COPD. In fact, workers who have little to no symptoms may never present to medical care in the first place. Those that do file claims may be inherently different from those with Occupational COPD in the general population. They likely have had longer duration to high risk exposures and may over-represent exposures that are already accepted to cause Occupational COPD, such as crystalline silica or cement dust. From the administrative perspective, claims may lack information because medical records were never received, or claims may have closed prior to performance of objective diagnostic testing due to administrative reasons such as incorrect filing.

Since WA L&I relies on passive surveillance methods, access to medical information remains limited. As such, the case capture criteria used by WA L&I to initially identify potential Occupational COPD claims are purposefully broad to avoid missing potential cases.

Of the claims with COPD ICD codes, it is suspected that some cases designated as *Not Valid, Work Aggravated,* or *Undetermined* may represent missed or misclassified cases. For many of the claims in these groups, information is incomplete for both COPD diagnosis and total career VGDF exposure. Misclassification may not affect the bottom line for the majority of cases in the *Not Valid* group, however, especially those designated as asthma or acute bronchitis. These cases would likely be captured in the asthma surveillance program, which would still allow for the appropriate direction of state resources toward exposure mitigation. For those in the *WA COPD* group, they are still included as “Occupational COPD” for surveillance purposes, and therefore would not be missed, although misclassification may impact access to appropriate health care services or limit mitigation of ongoing workplace exposures.

This study has many strengths. First, it includes a robust and semi-quantitative approach to VGDF exposure classification using a well-established and validated JEM. In past studies, VGDF exposures were often classified by self-reported “ever exposures” without clarifying duration or intensity. By using the JEM and documenting total career duration of exposure to high risk occupations, our study allows for a more granular and accurate assessment of risk and may potentially be used to identify novel causes of Occupational COPD. Second, our algorithm could conceivably be adapted to other health screening entities, such as other state or country-wide surveillance programs. Third, our algorithm can be used as a conceptual diagnostic framework in the clinical setting. It can be adapted to accommodate institutional preferences for COPD cutoff criteria and provides a framework for clinicians to categorize VGDF exposures. In addition to establishing risk by occupation, providers must also determine whether an exposure actually occurred. Providers may still use this algorithm as a framework while accounting for external factors that influence exposure such as engineering controls or personal protective equipment. Fourth, this algorithm allows for a more robust apportionment of risk based on smoking and VGDF exposures than expert opinion alone. And fifth, the algorithm allows for capture of mixed diagnostic cases such as asthma/COPD overlap or severe asthma with fixed post-bronchodilator obstruction that may represent particularly worrisome exposures such as Western Red Cedar[56].

Because this algorithm was developed for surveillance purposes, there are a few limitations that must be noted. As discussed previously, there is no universally accepted definition of COPD. The $FEV_1/FVC < 0.7$ based on GOLD criteria may underestimate COPD in the younger population while overestimating prevalence in the elderly[37]. In clinical practice, physicians often use the lower limit of normal (LLN)[25], although a cutoff of 0.70 may be more indicative of clinically relevant disease[48]. $FEV_1/FVC < 0.7$ was chosen for this study to allow for better comparison to large population studies, and because lower limit of normal is not available in a substantial proportion of claims filed for COPD. The lack of consensus diagnostic criteria, however, increases the chance of misclassification of cases. Second, complicated cases such as Fibrosis/COPD overlap may result in normalization of the FEV_1/FVC ratio, leading to misclassification. In our population, this affected only one or two cases and was considered an acceptable limitation. Third, there is no universally accepted minimum VGDF exposure that causes COPD. We chose five years to ensure adequate capture of cases that would benefit from intervention in the workplace. Our data are limited by records received by L&I, however, and this designation does not include latency from first exposure to development of disease. Fourth, the use of a JEM and occupation codes may misrepresent someone's true exposure. For example, an administrative assistant whose office is located on a construction site may have more ambient exposures than expected by occupation code. Also, the JEM classification does not account for protective conditions, such as engineering controls or personal protective equipment that may reduce an individual's exposure, leading to misclassification. Fifth, our analysis does not account for environmental or genetic causes of COPD, such as air pollution or alpha-1-antitrypsin deficiency. This is particularly important for cases designated as *Work Aggravated COPD*, with low or no smoking history. This group has limited information for further analysis but may suggest other environmental or genetic contributors for which the algorithm does not account.

In this study we have identified multiple industries and occupations with workers at risk of development of Occupational COPD. This algorithm provides clinicians and those in occupational safety and health with an opportunity to address an under-recognized need in a high risk population. Occupational COPD is a preventable condition that would benefit from further attention and diagnostic clarity.

Future directions:

The diagnosis of Occupational COPD is in need of reassessment and clarification. We hope this algorithm can be used to spark interest in a large collaboration of respiratory specialists to address some of the limitations in diagnosing and screening for Occupational COPD. We anticipate proposing a workshop to address this need at the next American Thoracic Society meeting in May, 2023. We also hope to collaborate with researchers in Canada on a systematic review of COPD and workplace exposures to better classify inclusion criteria for surveillance. This work was presented at the American Thoracic Society meeting in San Francisco in May, 2022. It will also be presented at the Building Trades Medical Screening Program for former Department of Energy Workers meeting 6/16/2022 and at the National Occupational Research Agenda Respiratory Health Cross-sector Council meeting in June or July 2022.

Acknowledgements:

We would like to acknowledge the significant work done by Danièle Todorov, epidemiologist at SHARP, and Suzanne Kelly, Database Management at SHARP, for their assistance with case capture, data management, and creation of our working database. In addition, I would like to acknowledge Carolyn Whitaker for her extensive assistance with claim disposition.

References:

1. Global Burden of Disease Data Visualization [cited 2021 April 24]; Available from: https://vizhub.healthdata.org/gbd-compare/.
2. Global Health Estimates: Life expectancy and leading causes of death and disability. The Global Health Observatory [cited 2021 April 28]; Available from: https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates.
3. Sullivan J, Pravosud V, Mannino DM, Siegel K, Choate R, Sullivan T. National and state estimates of COPD morbidity and mortality — United States, 2014-2015. Chronic Obstr Pulm Dis. 2018; 5(4): 324-333.
4. Blanc PD, Annesi-Maesano I, Balmes JR, Cummings KJ, Fishwick D, Miedinger D, Murgia N, Naidoo RN, Reynolds CJ, Sigsgaard T, Torén K, Vinnikov D, Redlich CA. The Occupational Burden of Nonmalignant Respiratory Diseases. An Official American Thoracic Society and European Respiratory Society Statement. Am J Respir Crit Care Med. 2019 Jun 1;199(11):1312-1334.
5. Wheaton AG, Liu Y, Croft JB, VanFrank B, Croxton TL, Punturieri A, Postow L, Greenlund KJ. Chronic Obstructive Pulmonary Disease and Smoking Status - United States, 2017. MMWR Morb Mortal Wkly Rep. 2019 Jun 21;68(24):533-538.
6. WHO global report on trends in prevalence of tobacco smoking 2000–2025, second edition. 2018, World Health Organization: Geneva.
7. Eisner MD, Anthonisen N, Coultas D, Kuenzli N, Perez-Padilla R, Postma D, Romieu I, Silverman EK, Balmes JR; Committee on Nonsmoking COPD, Environmental and Occupational Health Assembly. An official American Thoracic Society public policy statement: Novel risk factors and the global burden of chronic obstructive pulmonary disease. Am J Respir Crit Care Med. 2010 Sep 1;182(5):693-718.
8. Dement J, Welch L, Ringen K, Quinn P, Chen A, Haas S. A case-control study of airways obstruction among construction workers. Am J Ind Med. 2015 Oct;58(10):1083-97.
9. Omland Ø, Würtz ET, Aasen TB, Blanc P, Brisman JB, Miller MR, Pedersen OF, Schlünssen V, Sigsgaard T, Ulrik CS, Viskum S. Occupational chronic obstructive pulmonary disease: a systematic literature review. Scand J Work Environ Health. 2014 Jan;40(1):19-35.
10. Kleniewska A, Walusiak-Skorupa J, Lipińska-Ojrzanowska A, Szcześniak K, Wiszniewska M. Spirometric and hygienic criteria in recognition of occupational COPD in Poland - A retrospective analysis of medical records. Int J Occup Med Environ Health. 2018 Jan 7;31(2):139-150.
11. De Matteis S, Jarvis D, Darnton A, Hutchings S, Sadhra S, Fishwick D, Rushton L, Cullinan P. The occupations at increased risk of COPD: analysis of lifetime job-histories in the population-based UK Biobank Cohort. Eur Respir J. 2019 Jul 18;54(1):1900186.
12. Blanc PD, Iribarren C, Trupin L, Earnest G, Katz PP, Balmes J, Sidney S, Eisner MD. Occupational exposures and the risk of COPD: dusty trades revisited. Thorax. 2009 Jan;64(1):6-12.
13. NHANES Questionnaires, Datasets, and Related Documentation. [cited 2021 April 14]; Available from: https://wwwn.cdc.gov/nchs/nhanes/.
14. Balmes J, Becklake M, Blanc P, Henneberger P, Kreiss K, Mapp C, Milton D, Schwartz D, Toren K, Viegi G; Environmental and Occupational Health Assembly, American

Thoracic Society. American Thoracic Society Statement: Occupational contribution to the burden of airway disease. Am J Respir Crit Care Med. 2003 Mar 1;167(5):787-97.
15. Kuempel ED, Wheeler MW, Smith RJ, Vallyathan V, Green FH. Contributions of dust exposure and cigarette smoking to emphysema severity in coal miners in the United States. Am J Respir Crit Care Med. 2009 Aug 1;180(3):257-64.
16. Hnizdo E, Sullivan PA, Bang KM, Wagner G. Association between chronic obstructive pulmonary disease and employment by industry and occupation in the US population: a study of data from the Third National Health and Nutrition Examination Survey. Am J Epidemiol. 2002 Oct 15;156(8):738-46.
17. Hnizdo E, Vallyathan V. Chronic obstructive pulmonary disease due to occupational exposure to silica dust: a review of epidemiological and pathological evidence. Occup Environ Med. 2003 Apr;60(4):237-43.
18. Doney B, Kurth L, Halldin C, Hale J, Frenk SM. Occupational exposure and airflow obstruction and self-reported COPD among ever-employed US adults using a COPD-job exposure matrix. Am J Ind Med. 2019 May;62(5):393-403.
19. Doney B, Hnizdo E, Graziani M, Kullman G, Burchfiel C, Baron S, Fujishiro K, Enright P, Hankinson JL, Stukovsky KH, Martin CJ, Donohue KM, Barr RG. Occupational risk factors for COPD phenotypes in the Multi-Ethnic Study of Atherosclerosis (MESA) Lung Study. COPD. 2014 Aug;11(4):368-80.
20. Trupin L, Earnest G, San Pedro M, Balmes JR, Eisner MD, Yelin E, Katz PP, Blanc PD. The occupational burden of chronic obstructive pulmonary disease. Eur Respir J. 2003 Sep;22(3):462-9.
21. Syamlal G, Doney B, Mazurek JM. Chronic Obstructive Pulmonary Disease Prevalence Among Adults Who Have Never Smoked, by Industry and Occupation - United States, 2013-2017. MMWR Morb Mortal Wkly Rep. 2019 Apr 5;68(13):303-307.
22. Singh D, Agusti A, Anzueto A, Barnes PJ, Bourbeau J, Celli BR, Criner GJ, Frith P, Halpin DMG, Han M, López Varela MV, Martinez F, Montes de Oca M, Papi A, Pavord ID, Roche N, Sin DD, Stockley R, Vestbo J, Wedzicha JA, Vogelmeier C. Global Strategy for the Diagnosis, Management, and Prevention of Chronic Obstructive Lung Disease: the GOLD science committee report 2019. Eur Respir J. 2019 May 18;53(5):1900164.
23. Agustí A, Vogelmeier C, Faner R. COPD 2020: changes and challenges. Am J Physiol Lung Cell Mol Physiol. 2020 Nov 1;319(5):L879-L883.
24. Celli BR, MacNee W; ATS/ERS Task Force. Standards for the diagnosis and treatment of patients with COPD: a summary of the ATS/ERS position paper. Eur Respir J. 2004 Jun;23(6):932-46.
25. Pellegrino R, Viegi G, Brusasco V, Crapo RO, Burgos F, Casaburi R, Coates A, van der Grinten CP, Gustafsson P, Hankinson J, Jensen R, Johnson DC, MacIntyre N, McKay R, Miller MR, Navajas D, Pedersen OF, Wanger J. Interpretative strategies for lung function tests. Eur Respir J. 2005 Nov;26(5):948-68.
26. Fortis S, Comellas AP, Bhatt SP, Hoffman EA, Han MK, Bhakta NR, Paine R 3rd, Ronish B, Kanner RE, Dransfield M, Hoesterey D, Buhr RG, Barr RG, Dolezal B, Ortega VE, Drummond MB, Arjomandi M, Kaner RJ, Kim V, Curtis JL, Bowler RP, Martinez F, Labaki WW, Cooper CB, O'Neal WK, Criner G, Hansel NN, Krishnan JA, Woodruff P, Couper D, Tashkin D, Barjaktarevic I. Ratio of FEV_1/Slow Vital Capacity of < 0.7 Is

Associated With Clinical, Functional, and Radiologic Features of Obstructive Lung Disease in Smokers With Preserved Lung Function. Chest. 2021 Jul;160(1):94-103.
27. Yee N, Markovic D, Buhr RG, Fortis S, Arjomandi M, Couper D, Anderson WH, Paine R 3rd, Woodruff PG, Han MK, Martinez FJ, Barr RG, Wells JM, Ortega VE, Hoffman EA, Kim V, Drummond MB, Bowler RP, Curtis JL, Cooper CB, Tashkin DP, Barjaktarevic IZ. Significance of FEV_3/FEV_6 in Recognition of Early Airway Disease in Smokers at Risk of Development of COPD: Analysis of the SPIROMICS Cohort. Chest. 2022 Apr;161(4):949-959.
28. Surani S, Aiyer A, Eikermann S, Murphy T, Anand P, Varon J, Vanderheiden D, Khan A, Guzman A. Adoption and adherence to chronic obstructive pulmonary disease GOLD guidelines in a primary care setting. SAGE Open Med. 2019 Apr 4;7:2050312119842221.
29. Henneberger PK, Humann MJ, Liang X, Doney BC, Kelly KM, Cox-Ganser JM. The Association of Airflow Obstruction with Occupational Exposures in a Sample of Rural Adults in Iowa. COPD. 2020;17(4):401-409.
30. Fishwick D, Darby A, Hnizdo E, Barber C, Sumner J, Barraclough R, Bolton C, Burge S, Calverley P, Hopkinson N, Hoyle J, Lawson R, Niven R, Pickering T, Prowse K, Reid P, Warburton C, Blanc PD. COPD causation and workplace exposures: an assessment of agreement among expert clinical raters. COPD. 2013 Apr;10(2):172-9.
31. US Bureau of Labor Statistics, 2002 Census Industry Codes. [cited 2022 May 9]; Available from:https://www.bls.gov/tus/census02iocodes.pdf
32. Coughlin SS, Chiazze L Jr. Job-exposure matrices in epidemiologic research and medical surveillance. Occup Med. 1990 Jul-Sep;5(3):633-46. PMID: 2218806.
33. Reeb-Whitaker C, LaSee C. Washington State’s occupational respiratory disease surveillance system, 2016 – 2017: Surveillance methods and a preliminary evaluation. 2019. First Annual Report, Publication # 64-14-2019
34. WRA State Reporting Guidelines. 2012 [cited 2021 April 28]; Available from: https://www.cdc.gov/niosh/topics/surveillance/ords/statesurveillance/reportingguidelines-wra.html#guidelines.
35. Classification of Diseases, Functioning, and Disability. National Center for Health Statistics 2021 July 23, 2021 [cited 2022 May 9]; Available from: https://www.cdc.gov/nchs/icd/index.htm.
36. Occupational Injury and Illness Classification Manual. Injuries, Illnesses, and Fatalities February 3, 2021 [cited 2021 May 16]; Available from: https://www.bls.gov/iif/oshoiics.htm.
37. Vestbo, J., et al., Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: GOLD executive summary. Am J Respir Crit Care Med, 2013. 187(4): p. 347-65.
38. Centers for Disease Control and Prevention, National Center for Health Statistics. National Health Interview Survey: Adult Tobacco Use Information, Glossary. 2017 [cited 2021 May 5]; Available from: https://www.cdc.gov/nchs/nhis/tobacco/tobacco_glossary.htm.
39. Blanc PD, Eisner MD, Earnest G, et al. Further exploration of the links between occupational exposure and chronic obstructive pulmonary disease. J Occup Environ Med. 2009;51(7):804-810. doi:10.1097/JOM.0b013e3181a7dd4e

40. Park H, Jung SY, Lee K, Bae WK, Lee K, Han JS, Kim S, Choo S, Jeong JM, Kim HR, Ro HJ, Jeong H. Prevalence of chronic obstructive lung disease in Korea using data from the fifth Korea national health and nutrition examination survey. Korean J Fam Med. 2015 May;36(3):128-34.
41. [31]Standard Occupational Classification (SOC) User Guide. 2000 [cited 2021 April 28]; Available from: https://www.bls.gov/soc/2000/socguide.htm#:~:text=The%202000%20Standard%20Occupational%20Classification,industry%20to%20produce%20comparable%20data.
42. Search NAICS Codes by Industry. [cited 2021 May 16]; Available from: https://www.naics.com/search-naics-codes-by-industry/.
43. Blanc PD, Ellbjär S, Janson C, Norbäck D, Norrman E, Plaschke P, Torén K. Asthma-related work disability in Sweden. The impact of workplace exposures. Am J Respir Crit Care Med. 1999 Dec;160(6):2028-33.
44. Association of Occupational and Environmental Clinics exposure code lookup. AOEC 2009 - 2012. [cited 2022 May 9]; Available from:http://www.aoecdata.org/expcodelookup.aspx
45. North America Building Trades Unions. Response to the Office of Workers Compensation Programs Energy Employees Occupational Illness Compensation Act Bulletin No: 16-02. [cited 2022 May 21]; Available from: https://www.dol.gov/sites/dolgov/files/owcp/energy/regs/compliance/advboard/nabtu_copd_comments.pdf
46. Vinnikov D, Raushanova A, Kyzayeva A, Romanova Z, Tulekov Z, Kenessary D, Auyezova A. Lifetime Occupational History, Respiratory Symptoms and Chronic Obstructive Pulmonary Disease: Results from a Population-Based Study. Int J Chron Obstruct Pulmon Dis. 2019 Dec 30;14:3025-3034.
47. Azaroff LS, Levenstein C, Wegman DH. Occupational injury and illness surveillance: conceptual filters explain underreporting. Am J Public Health. 2002 Sep;92(9):1421-9. doi: 10.2105/ajph.92.9.1421. PMID: 12197968; PMCID: PMC1447253.
48. Bhatt SP, Balte PP, Schwartz JE, Cassano PA, Couper D, Jacobs DR Jr, Kalhan R, O'Connor GT, Yende S, Sanders JL, Umans JG, Dransfield MT, Chaves PH, White WB, Oelsner EC. Discriminative Accuracy of FEV1:FVC Thresholds for COPD-Related Hospitalization and Mortality. JAMA. 2019 Jun 25;321(24):2438-2447.
49. Carder M, Darnton A, Gittins M, Stocks SJ, Ross D, Barber CM, Agius RM. Chest physician-reported, work-related, long-latency respiratory disease in Great Britain. Eur Respir J. 2017 Dec 28;50(6):1700961. doi: 10.1183/13993003.00961-2017. PMID: 29284684.
50. Tilert T, Paulose-Ram R, Howard D, Butler J, Lee S, Wang MQ. Prevalence and factors associated with self-reported chronic obstructive pulmonary disease among adults aged 40-79: the National Health and Nutrition Examination Survey (NHANES) 2007-2012. *EC Pulmonol Respir Med*. 2018;7(9):650-662.
51. Buist AS, Vollmer WM, McBurnie MA. Worldwide burden of COPD in high- and low-income countries. Part I. The burden of obstructive lung disease (BOLD) initiative. Int J Tuberc Lung Dis. 2008 Jul;12(7):703-8. PMID: 18544191.
52. Global Strategy for the Diagnosis, Management, and Prevention of Chronic Obstructive Pulmonary Disease, 2022 Report. Published by Global Initiative for Chronic Obstructive

Lung Disease (GOLD). [cited 2022 May 23]; Available from: https://goldcopd.org/2022-gold-reports-2/

53. Han MK, Arteaga-Solis E, Blenis J, Bourjeily G, Clegg DJ, DeMeo D, Duffy J, Gaston B, Heller NM, Hemnes A, Henske EP, Jain R, Lahm T, Lancaster LH, Lee J, Legato MJ, McKee S, Mehra R, Morris A, Prakash YS, Stampfli MR, Gopal-Srivastava R, Laposky AD, Punturieri A, Reineck L, Tigno X, Clayton J. Female Sex and Gender in Lung/Sleep Health and Disease. Increased Understanding of Basic Biological, Pathophysiological, and Behavioral Mechanisms Leading to Better Health for Female Patients with Lung Disease. Am J Respir Crit Care Med. 2018 Oct 1;198(7):850-858.
54. Birring SS, Brightling CE, Bradding P, Entwisle JJ, Vara DD, Grigg J, Wardlaw AJ, Pavord ID. Clinical, radiologic, and induced sputum features of chronic obstructive pulmonary disease in nonsmokers: a descriptive study. Am J Respir Crit Care Med. 2002 Oct 15;166(8):1078-83.
55. Chapman KR, Tashkin DP, Pye DJ. Gender bias in the diagnosis of COPD. Chest. 2001 Jun;119(6):1691-5.
56. Chan-Yeung M. Fate of occupational asthma. A follow-up study of patients with occupational asthma due to Western Red Cedar (Thuja plicata). Am Rev Respir Dis. 1977 Dec;116(6):1023-9.