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WORK RELATED ASTHMA



Surveillance of work-related asthma including the emergence of a cannabis-associated case series in Washington State

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ABSTRACT

Objective: We conducted surveillance for work-related asthma (WRA) in Washington State to identify the industry sectors and asthma exposures most commonly affecting injured workers and in need of prevention activities.

Methods: Using workers' compensation data as the primary data source, valid cases were classified as work-aggravated asthma (WAA) or new onset asthma that includes occupational asthma (OA) and reactive airways dysfunction syndrome (RADS). The source of exposure that caused the worker's asthma, their industry and occupation were determined.

Results: There were 784 valid work-related asthma cases identified for the period 2009–2016, WAA ($n=529$) was most common followed by occupational asthma ($n=127$) and RADS ($n=12$). The Health Care and Social Assistance industry had the highest number of cases ($n=170$) with 82% classified as WAA. The highest overall proportions of new onset asthma are occurring in Agriculture, Forestry, Fishing and Hunting (33% of work related asthma cases), Manufacturing (31%) and Construction (30%). The leading substances associated with new onset asthma across all industries include hop plant dust, wood and cedar dust, mineral and inorganic dust, mold, and cleaning materials. We describe ten cases of cannabis-associated asthma including seven from workers in the legalized cannabis industry, four of whom had OA.

Conclusion: State-based work-related asthma surveillance is critical in identifying the workers and exposures associated with this occupational disease, including the detection of a case-series in the cannabis industry.

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Introduction

Work-related asthma (WRA) surveillance can inform prevention activities taken on by employers, safety and health professionals, and healthcare providers. Surveillance for WRA includes occupational asthma with latency, asthma without latency (e.g. Reactive Airways Dysfunction Syndrome (RADS)) and aggravation of symptomatic asthma due to exposures found in the workplace. It is estimated that 15 to 16% of new-onset adult asthma is attributable to workplace exposures (1,2). Epidemiological studies conducted in general populations indicate the median prevalence of work-aggravated asthma is 21.5% (range 13% to 58%) among adults with asthma (3). Groenewold et al. (4) summarizes that the relative risk of WRA ranges from 1.48 to 2.40 and estimates that occupational exposures were therefore responsible for 11.71% to 25.93% of all incident US asthma cases or approximately 108 000 to 262 000 cases in 2012 (5,6).

Previously published surveillance data from Washington State for the period 2002 to 2016 demonstrate WRA rates vary by industry (7,8). Industry sectors with high rates of WRA include: Public Administration (12.1 cases per 100 000 Full Time Equivalent (FTE)); Manufacturing (9.5 cases per 100 000 FTE); and Agriculture, Forestry, Fishing and Hunting (8.9 cases per 100 000 FTE) (7). The WRA rates for Educational Services; Health Care and Social Assistance; and Administrative and Support and Waste Management and Remediation Services range from 8.2 to 8.3 cases per 100 000 FTE in each industry (7). While the Construction industry does not have a comparably high WRA rate it does hold a high percentage of workers' compensation costs, along with Manufacturing, at 16.4 and 21.3%, respectively, for all WRA claims filed between 2002–2016 (7). In comparison, national data pooled across 21 states indicate that the industries with the highest percent of current

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asthma prevalence among employed adults are Health Care and Social Assistance (10.7%); Education (9.1%); and the Arts, Entertainment, and Recreation (9.0%) (9).

Occupational respiratory disease surveillance provides an opportunity to identify new or emerging workplace exposures that put workers at risk for disease. As such, we present a series of work-related asthma cases in Washington State's legalized medical and recreational cannabis (marijuana) industry. Washington State legalized medical cannabis in 1998 and recreational cannabis use and sales in 2012. As of April 2021, medical marijuana was legal in 36 U.S. states as well as the District of Columbia, Guam, Puerto Rico, and the U.S. Virgin Islands while recreational marijuana was legal in 17 U.S. states, the District of Columbia, Guam, and the Northern Mariana Islands. The causal relationship between cannabis exposure and respiratory disease is complex (10,11). Cannabis was historically shown to have a mild bronchodilator effect and was therefore prescribed to treat asthma, but it is more recently recognized to cause asthma through respiratory sensitization (11–14). An occupational cross-sectional study in a modern indoor cannabis grow facility in Washington State found high prevalence of work-related allergic and respiratory symptoms among 31 employees, 10 of whose work-aggravated symptoms were consistent with probable work-related asthma based on fractional exhaled nitrogen oxide (FeNO), airflow obstruction on spirometry, and cannabis sensitization on skin prick testing (15). However 97% of study subjects were recreational cannabis users, making it difficult to ascribe health effects exclusive to the work environment (15). A review article by Ocampo et al. (10) describes multiple allergic diseases and reactions to *Cannabis sativa* associated with cannabis use, pollen exposure, plant cross-reactivity and occupational exposure. Occupational reports include two cases of allergic asthma (one in the occupational setting of a bird breeder exposed to *Cannabis sativa* seed); a reduction in lung function in hemp workers; and urticaria and hypersensitivity reactions in cannabis laboratory workers (16–21). Efforts to identify specific allergens have been undertaken with several potential allergens of *C. sativa* identified, including Delta-9-tetrahydrocannabinol (THC), Can s 3, RuBisCO, and others (10,13,18,22–24). Very little is known about the occupational inhalation or dermal exposure experienced by cannabis production and retail workers.

The purpose of this study is to provide an eight-year update for the years 2009 through 2016 for

work-related asthma surveillance in Washington State. Detailed information on asthma classification and exposure agent by industry is given. State-based surveillance can identify emerging trends specific to the regional population and we describe in detail a new case series for cannabis-associated asthma in the legalized cannabis industry.

Materials and methods

Surveillance data source

The primary data source for this report is the Washington State workers' compensation (WC) data. In Washington State, all employers must obtain WC insurance through the State Fund (SF) insurance program administered by the Washington State Department of Labor and Industries (L&I) (25). About 72% of all employees and 99.7% of employers are covered through the SF. Exemptions to the mandatory SF coverage include insurance through an alternative WC program (e.g. Federal Employees' Compensation Act, Longshore and Harbor Workers' Compensation Act), self-employment, a small number of statutory exemptions for specific occupations or employment arrangements, or employers who meet the requirements to self-insure (26,27). The Washington State Department of Labor and Industries provides oversight of self-insured employers and while a limited dataset is available for analysis, the data are less complete for the purpose of WRA surveillance. As a result, the surveillance system described here reflects primarily SF insured workers. Health care providers may also confidentially report cases of suspected WRA directly to the surveillance program regardless of insurance coverage, following Washington State's Notifiable Conditions rule (28).

Asthma surveillance system

Washington's work-related asthma surveillance system commenced in 2001 and has been previously described (7,8). Suspected cases are identified by searching the Report of Accident (ROA) form for all filed claims for the keyword 'asthma.' The ROA includes an employee description of the injury event and a health care provider's diagnoses pertaining to the suspected occupational injury or disease. Potential claims are extracted monthly and imported into the surveillance system database. An analyst reviews the ROA, administrative insurance records, and medical records to verify that the claim was filed for WRA. Educational materials are mailed to all claimants with WRA along

with a letter stating that our surveillance program may call them for a telephone interview.

Asthma classification and exposure coding

The surveillance program follows the Sentinel Event Notification System for Occupational Risks (SENSOR) case classification scheme for occupational asthma adopted by the National Institute for Occupational Safety and Health (NIOSH) (29). Cases are classified as being either work-aggravated asthma (WAA) or new-onset asthma (NOA). NOA cases are further classified as occupational asthma with latency (OA) or new-onset asthma without latency known as reactive airways dysfunction syndrome (RADS) (29,30). Workers with a history of symptomatic or treated asthma within two years of entering a new occupational exposure setting and who experience an increase in symptoms or an increase in the use of asthma medication upon entering a new work setting are classified as WAA (29). Occupational asthma refers to classic sensitizer-induced asthma with latency caused by agents that may or may not be previously documented in the medical literature as causes of occupational asthma. RADS or occupational asthma without latency is defined as persistent asthma-like symptoms lasting for at least three months induced within 24 h to a one-time high-level irritant exposure (29,30). The clinical criteria for RADS includes an absence of preceding respiratory complaints, pulmonary function tests that may show airflow obstruction, and positive bronchial challenge test (30). Valid cases are classified for asthma type regardless of their WC claim adjudication status; they may be accepted, rejected, pending, or other.

Up to five exposures are ascribed to each WRA case to define the agent(s) that gave rise to their asthma. Exposure codes are those established by the Association of Occupational and Environmental Clinics' (AOEC) hierarchical exposure coding system and includes codes for chemicals, metals, dusts, plants, animals, and physical hazards such as cold temperatures (31).

Asthma classification and exposure code assignment are determined after six months of claim maturation using information from the injured worker's medical record or if needed a telephone questionnaire is administered. The medical record may comprise records from more than one medical provider including medical specialists such as a pulmonologist, and may contain information such as diagnoses, past medical history, treatment plan including return-to-work, and context for the work-related exposures including

Safety Data Sheets. Injured workers with incomplete records are interviewed over the telephone with a questionnaire to ascertain their asthma classification and exposure. Cases with incomplete records and without a phone interview are classified as undetermined.

Cannabis case-series

In response to three emerging cases of cannabis-associated asthma observed in our surveillance system, two additional steps were taken to look for additional cannabis-associated asthma cases within the WC data. First, we queried the work-related asthma surveillance system from its inception in 2002 through 2019 for cannabis-associated cases. This expanded the scope of years for the cannabis case series beyond the 2009–2016 surveillance dataset otherwise presented in detail here. Second, we queried the entire WC database for any claim filed by workers in the legalized cannabis industry for any reason. We identified industry employers using the Unified Business Identifier (UBI) associated with their cannabis industry license issued through the regulating authority of the Washington State Liquor and Cannabis Board. The UBI is a unique identifier and was used to identify workers' compensation claims filed by cannabis industry employers. All cannabis industry claims were reviewed to identify those specific to cannabis exposure and respiratory health effects.

Analyses were conducted in SAS v9.4 and Microsoft Office Professional Plus Excel 2016. The Washington State Institutional Review Board approved all surveillance protocols and materials used by the WRA surveillance program.

Results

A total of 784 valid WRA cases were identified for the period 2009–2016. The majority of cases were classified as work-aggravated asthma ($n=529$) compared to occupational asthma ($n=127$) and RADS ($n=12$) with just under 15% of all cases unclassifiable (Table 1). Females experienced a higher proportion of WAA (67%) while males experienced a higher proportion of OA (58%, Table 1). The percent of workers' compensation claims that were accepted was similar for all types of asthma classification, ranging from 50 to 56% but was low for unclassified cases (29%, Table 1). The surveillance system identified an annual average of 98 cases (SD = 10.4; Figure 1). A high proportion of

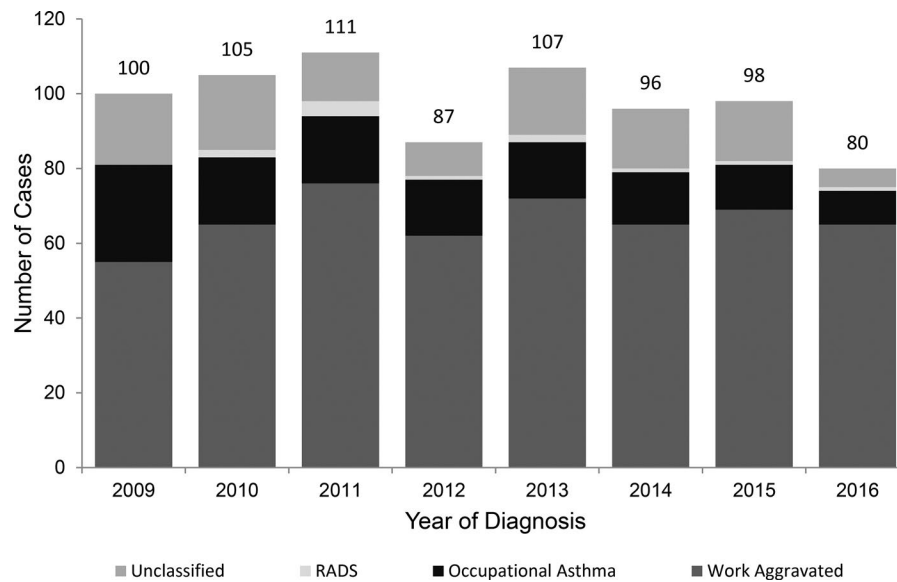


Figure 1. Work-related asthma annual case count, WA State 2009–2016.

Table 1. Case count, sex, and claim acceptance rate by work-related asthma classification, 2009–2016.

Asthma classification	CaseCount	Sex, n (%)		% Claim Acceptance
		Male	Female	
New Onset Asthma (NOA)				
Occupational Asthma (OA)	127	74 (58)	53 (42)	56
Reactive Airways Dysfunction Syndrome (RADS)	12	5 (42)	7 (58)	50
Work Aggravated Asthma (WAA)	529	175 (33)	354 (67)	52
Unclassified	116	65 (56)	51 (44)	29
Total	784	319 (41)	465 (59)	50

NOA was observed in four industry sectors including Agriculture (33%), Manufacturing (31%), Construction (30%), and Wholesale Trade (28%, [Figure 2](#)). More specifically, agriculture cases occur in the industry groups of Fruit and Tree Nut Farming while most

Manufacturing cases occur amongst Aerospace Product and Parts Manufacturing ([Table 2](#)). The industry sector with the highest total prevalence of WRA is Health Care and Social Assistance (102 cases, [Figure 2](#)) and these cases occur in the industry groups of General

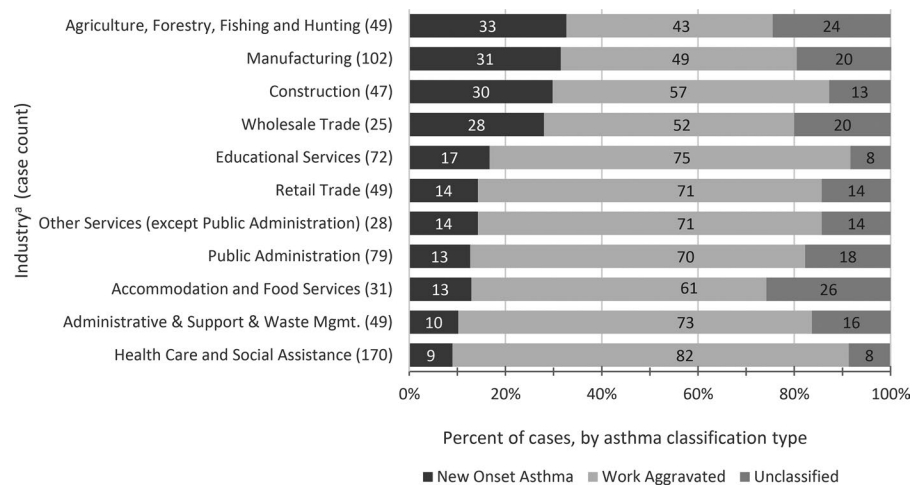


Figure 2. Distribution of work-related asthma across 11 major industry sectors ($n=701$), 2009–2016. *Notes:* ^aIndustry sector by North American Industry Classification System (NAICS). Sectors with 20 or fewer cases are not shown (n): Professional, Scientific, Technical (20), Transportation & Warehousing (16), Real Estate and Rental Leasing (13), Information (9), Finance and Insurance (8), Arts, Entertainment & Recreation (5), Utilities (2), Mining (1), and industry sector Unknown (9).

Table 2. Industry groups with the majority of work-related asthma cases, for the top 11 industry sectors.

Industry Sector (NAICS ^a , 2-digit) and Industry Group (4-digit)	Case Count
Healthcare and Social Assistance (62)	
General Medical and Surgical Hospitals (6221)	64
Offices of Physicians (6211)	27
Nursing Care Facilities (Skilled Nursing Facilities, 6231)	11
Continuing Care Retirement Comm. & Assisted Living Facilities (6233)	12
Manufacturing (31–33)	
Aerospace Product and Parts Manufacturing (3364)	27
Sawmills and Wood Preservation (3211)	10
Public Administration (92)	
Executive, Legislative, and Other General Government Support (9211)	32
Justice, Public Order, and Safety Activities (9221)	16
Administration of Human Resource Programs (9231)	16
Administration of Environmental Quality Programs (9241)	10
Education Services (61)	
Elementary and Secondary Schools (6111)	28
Colleges, Universities, and Professional Schools (6113)	38
Agriculture, Forestry, Fishing and Hunting (11)	
Fruit and Tree Nut Farming (1113)	20
Other Crop Farming (including hay) (1119)	11
Support Activities for Crop Production (1151)	11
Retail Trade (44–45)	
Automobile Dealers (4411)	8
Administrative & Support & Waste Mgmt. & Remediation Svcs (56)	
Employment Services (5613)	16
Services to Buildings and Dwellings (5617)	15
Construction (23)	
Building Finishing Contractors (2383)	11
Building Equipment Contractors (2382)	13
Accommodation and Food Services (72)	
Limited-Service Eating Places (7222)	10
Other Services (except Public Administration, 81)	
Automotive Repair and Maintenance (8111)	6
Business , Professional Labor, Political, and Similar Organizations (8139)	6
Wholesale Trade (42)	
Grocery and Related Product Merchant Wholesalers (4244)	8

Notes: ^aNorth American Industry Classification System (NAICS).

Medical and Surgical Hospitals; Physician Offices; Nursing Care Facilities; and Retirement and Assisted Living Facilities (Table 2).

The leading exposures associated with new-onset asthma are plant material (all types), miscellaneous chemicals, and dusts that are mineral, inorganic, and not otherwise specified (Table 3). Substances associated more frequently with NOA and less often with WAA are isocyanates, polymers, and chlorine products. In contrast, substances more frequently associated with WAA are indoor air pollutants, smoke, perfume, and stress and exercise (Table 3). A detailed breakdown of the substances associated with NOA and WAA, by industry sector for the 11 industries having high WRA prevalence and illustrated in Figure 2 is shown in Table 4.

Cannabis case series

A total of ten valid cannabis-associated cases were identified for the period 2002–2019. The first case in

Table 3. Top exposure agents^a, by asthma classification, for 784 work-related asthma cases.

New Onset Asthma	Count ^b	Work-Aggravated Asthma	Count
Plant Material (All)	36	Indoor air pollutants	77
Miscellaneous chemicals	21	Cleaning materials	68
Dust, mineral, inorganic, & NOS ^c	16	Smoke	62
Cleaning materials	14	Plant Material (All)	56
Animal Material	13	Dust, mineral, inorganic, & NOS	55
Hydrocarbons, NOS	12	Perfume	53
Isocyanates	11	Mold	47
Smoke	11	Miscellaneous chemicals	47
Mold	8	Hydrocarbons, NOS	25
Metals	8	Stress & exercise	20
Polymers	7	Animal Material	19
Chlorine products	6	All Other	112
All Other	37	Total	641
Total	200		
Asthma Classification	Count		
Unknown			
Dust, mineral, inorganic & NOS	19		
Miscellaneous chemicals	13		
Indoor air pollutants	11		
Mold	9		
All Other	59		
Total	111		
Cumulative total of all substances	952		

Notes: ^aExposure agents defined by the Association of Occupational and Environmental Clinics exposure code system. ^bCases may be assigned between one and five unique substance codes. ^cNot Otherwise Specified (NOS).

the series arose in a police officer/evidence room manager in 2005 (Table 5). The first case from an employed worker in the legalized cannabis industry occurred in 2015 (legalization of recreational use and sales occurred in 2012), with the remaining cases occurring at least annually thereafter through 2019. The ten cannabis-associated cases involved cannabis dust, fume, or smoke as contributors to the etiology of the respiratory disease (Table 5). Seven cases arose directly out of the legalized cannabis grow industry (cases 2 through 8), three of whom had new-onset occupational asthma. All cannabis industry workers were from indoor grow facilities and described their occupation as cannabis trimmer, processor, and operations manager. These workers were engaged in the growing, tending, processing, packaging, and sale of cannabis.

The clinical evaluation of the cannabis-associated cases varied (Table 5). Typically, a brief history and physical exam were performed with no quantitative assessments for reversible obstructive lung disease. Among the seven cannabis industry workers with exposure to whole cannabis plants and dust, three had upper respiratory symptoms (cases 2, 3, and 8), and two cases had dermal symptoms – urticaria and

Table 4. Substances associated with work-related new onset asthma or work-aggravated asthma, by industry sector (NAICS^a) for the cases presented in Figure 2. Industries with the highest number of new-onset asthma cases are listed first. Cases with unknown substance codes are not included.

	New Onset Asthma	Work-Aggravated Asthma
Manufacturing	32 cases, 49 substance codes Wood dust (5); Western red cedar (5); Mineral & inorganic dust (5); Isocyanates (5); Metals (5); Plant material NOS (4); Misc. chemicals (3); Polymers (3); Solvents (3); Ketones (2); Chlorine dioxide (2); Welding fume (2); All other (5)	50 cases, 61 substance codes Plant material NOS (6); Wood dust (5); Misc. chemicals (5); Mineral & inorganic dust (4); Solvents (4); Acids (4); Metals (4); Smoke NOS (4); Ketones (3); Indoor Air Pollutants (3); Western red cedar (2); All other (17)
Agriculture, Forestry, Fishing & Hunting	16 cases, 18 substance codes Hops (8); Misc. chemicals (8); Inorganic compounds (1); Plant material NOS (1)	21 cases, 27 substance codes Hops (7); Misc. chemicals (6); Mineral & inorganic dust (4); Hydrocarbons NOS (2); Cleaning materials (2); Plant material NOS (2); Smoke NOS (2); Marijuana Smoke (1); Cold temp (1)
Health Care & Social Assistance	16 cases, 23 substance codes Mold (5); Cleaning materials (3); Misc. chemicals (2); Aliphatic & alicyclic hydrocarbons (2); Indoor air pollutants (2); Smoke cigarette (2); Marijuana Smoke (1); All Other (6)	140 cases, 156 substance codes Indoor air pollutants (26); Perfume (25); Cleaning materials (20); Misc. chemicals (12); Mold (10); Smoke NOS (7); Smoke Cigarette (7); Marijuana Smoke (1); All Other (48)
Construction	14 cases, 15 substance codes Mineral & inorganic dust (4); Misc. chemicals (2); Epoxies (2); and 1 case each for Indoor air pollutants, Isocyanates, Mold, Solvents, Wood dust, Western red cedar, and Welding fume	27 cases, 38 substance codes Mineral & inorganic dust (14); Metals (5); Wood dust (3); Plant material NOS (2); Western red cedar (2); Animal material NOS (2); Aliphatic & alicyclic hydrocarbons (2); Smoke NOS (2); All Other (6)
Educational Services	12 cases, 22 substance codes Cleaning materials (4); Animal material (4); Metals (welding fume) (2); Chlorine products (2); Mineral & inorganic dust (2); Wood dust (2); All Other (6)	54 cases, 72 substance codes Indoor air pollutants (13); Cleaning materials (10); Mineral & inorganic dust (7); Misc. chemicals (6); Mold (6); Perfume (6); Smoke NOS (5); Exercise/Stress (3); Exhaust diesel or engine (3); Disinfectants (3); Plant material NOS (2); All Other (8).
Public Administration	10 cases, 12 substance codes Smoke NOS (4); Aromatic hydrocarbons (2); Chlorine (2); and 1 each for Chloramine, Cleaning materials, Polymer, and Alcohol.	55 cases, 64 substance codes Mold (14); Indoor air pollutants (14); Plant material NOS (6); Cleaning materials (6); Exercise/Stress (6); Perfume (3); All Other (15)
Retail Trade	7 cases, 12 substance codes Solvents (2); and 1 case each for Butyl Acetate, Cleaning materials, Glycol ethers, Hydrogen sulfide, Isocyanate, Polymer, Plant material NOS, Misc. chemical, Wood dust, Western red cedar	35 cases, 44 substance codes Indoor air pollutants (6); Cleaning materials (5); Exercise/Stress (4); Perfume (3); Mold (3); Plant material NOS (3); Cold temperature (2); Misc. chemicals (3); Acids (2); All Other (13)
Wholesale Trade	7 cases, 8 substance codes Plant material NOS (2), Cleaning materials (2), 1 case each for hops, wood dust, ozone and misc. chemicals	13 cases, 14 substance codes Perfume (2); Plant material NOS (2); All Other (10)
Admin Support & Waste Management	5 cases, 7 substance codes Mineral & inorganic dust (2) and 1 case each for Polymers, Cleaning materials, Smoke NOS, Aliphatic & Alicyclic hydrocarbons, Solvents	36 cases, 46 substance codes Mineral & inorganic dust (7); Cleaning materials (6); Misc. chemicals (5); Mold (4); Plant material NOS (4); Animal material (3); Smoke NOS (3); Metals (2); Polymers (2); Indoor air pollutants (2); All Other (8)

Notes: ^aNorth American Industry Classification System (NAICS).

pruritis (cases 2 and 3, respectively). Case 4 had spirometry with medical records reporting a 27% improvement in the forced expiratory volume in one second (FEV1) following bronchodilator treatment. Case 8 had a reported change in peak expiratory flow rate from 240 to 448 liters per minute after treatment with a bronchodilator. All cases had medical treatment consisting of prescribed short and long-acting bronchodilators, inhaled corticosteroids or leukotriene inhibitors. Four of the ten cannabis-associated cases were adjudicated as accepted workers' compensation claims, and six were rejected. One claim (case #4) was compensable with medical and time loss compensation costs for the life of the claim estimated at \$176 000. Nine cases were medical-only claims with a median cost of \$423.

Discussion

Public health surveillance is meant to identify emerging causes of disease. Marijuana (*Cannabis* spp.) was legalized in Washington State for medical use in 1998 and for adult recreational use in 2012. Case counts of cannabis-associated WRA increased from one case in the 11 years prior to recreational legalization to nine cases in the years following legalization. In the context of our state surveillance data, this is a notable and sudden increase in cases, though small in number, the majority of which arise directly from the newly legalized recreational cannabis industry. Because the underreporting of cases is common in surveillance, we anticipate that the cases we have identified to date underestimate the true burden of respiratory disease in cannabis

Table 5. Cannabis-associated work related asthma case series.

Case #	Asthma Classification ^a	Year, Industry (NAICS ^b), Job Title	Case Description ^c
1	WAA	2005 Police Protection (922120) <i>Evidence Room Manager</i>	A man in his 50's with preexisting asthma experienced increasingly frequent asthma exacerbations from continued handling of marijuana and marijuana paraphernalia stored in an unventilated evidence room. He was also exposed to wet, moldy evidence items. He was accommodated with short-term alternative work with no exposure to marijuana. His symptoms resolved in a week leading to his return to full-time work in the job of injury.
2	WAA	2015 Other Food Crops Grown Under Cover (111419) <i>Processor</i>	A woman in her 20's with preexisting asthma working as a processor chopped and ground cannabis plants in a commercial food processor. Her symptoms began on the first day of work with sneezing, shortness of breath, watery eyes, and hives. Her shortness of breath progressed in severity throughout her first month on the job. She quit employment and her symptoms resolved over the course of five weeks. She had no previous exposure to cannabis.
3	WAA	2016 Other Food Crops Grown Under Cover (111419) <i>Processor</i>	A man in his late 20's with preexisting asthma noticed pruritus, conjunctivitis, and rhinorrhea accompanied by shortness of breath and chest tightness after his first shift trimming cannabis. Over the next two weeks, his symptoms increased with each subsequent trimming shift. He transitioned to work in the labeling department with reduced exposure. His skin symptoms persisted, however, and he left employer several weeks later.
4	WAA	2016 Other Food Crops Grown Under Cover (111419) <i>Trimmer</i>	A woman in her 50's with preexisting asthma was employed for one year in a cannabis grow facility where she trimmed, packaged, and weighed cannabis. After one year, she had an asthma exacerbation that forced her to be permanently removed from work. Her wheezing and dyspnea improved over an eight-week period of removal from the work environment. Her work exposures were notable for mold on the cannabis plants and heavy use of aerosolized rubbing alcohol for cleaning. Review of medical records over a five-year follow-up period, indicate she had severe persistent asthma and had not returned to work.
5	OA	2016 Other Food Crops Grown Under Cover (111419) <i>Trimmer</i>	A man in his late 20's without a history of asthma had a 14-month history of trimming cannabis plants at a growing operation, when he developed wheezing, cough, and shortness of breath associated with exposure to a white powder – 'mildew/mold' growing on the cannabis plants. Removal from work for three days with medical treatment led to symptom resolution. Upon return to work he wore a dusk mask and was reportedly symptom-free.
6	OA	2017 Offices of All Otr. Misc. Health Practitioners (621399) <i>Operations manager</i>	A man in his 30's without a history of asthma noticed during his 3 rd year of employment at a cannabis growing operation, episodic symptoms of cough, wheeze and shortness of breath. His respiratory symptoms were temporally associated with exposure to the chopping and grinding dried cannabis. He was diagnosed with acute bronchospasm. He was subsequently lost to follow-up after his single urgent care visit.
7	OA	2018 Other Food Crops Grown Under Cover (111419) <i>Processor</i>	A man in his 20's experienced shortness of breath and wheeze while working at a cannabis grow operation for 2 months. He had experienced similar symptoms working at a cannabis grow operation 2 years prior with no symptoms in the interval between the two work exposures. He was diagnosed with asthma from cannabis. He was advised to 'completely avoid exposure to cannabis smells or residues' and 'to consider changing professions.' He was referred to occupational medicine and his workers' compensation claim was accepted, however, the worker withdrew the claim and no further medical information was obtained.
8	OA	2019 Offices of All Otr. Misc. Health Practitioners (621399) <i>Processor/Packaging</i>	A man in his 20's with seasonal allergies but no history of asthma presented after four months working at a marijuana grow operation. In his first week, he reported 'allergy attacks' of sneezing, runny nose and irritation during his job where he weighed and packaged cannabis products with 'little ventilation.' In the first month, he had the onset of wheeze, shortness of breath and chest tightness that would last one or more days with occasional nighttime flare-ups. He was diagnosed with possible asthma, treated for allergy symptoms, advised to return to work, and was referred to occupational medicine for an asthma evaluation. He did not attend the referral and no further medical information was obtained.
9	WAA	2016 Otr. Res. Care (623990) <i>Program manager</i>	A juvenile detention center manager in her 40's with preexisting asthma experienced an exacerbation from unexpected exposures to cannabis and cigarette smoke.
10	WAA	2018 Otr. Fam. Svcs. (624190) <i>Case manager</i>	A social services case manager in her 50's with preexisting asthma exposed to cannabis, methamphetamine and heroin fumes during a check-in at a client's apartment.

Notes: ^aWAA, work-aggravated asthma; OA, occupational asthma. ^bNorth American Industry Classification System (NAICS). ^cAll workers had treatment for their asthma usually with a combination of short or long acting inhaled beta-agonists, inhaled or oral steroids and/or nasal steroids.

workers. The seven cases from within the legalized cannabis industry are associated with tasks such as grow, harvest, trim, process, and package. These

industry workers had exposure to whole plant dust, possibly in high doses, for full workdays and three cases described working under poor indoor ventilation.

All valid cases, including the cannabis-associated cases, meet a public health surveillance system definition for WRA and are identified from a state workers' compensation program meant to provide benefits for work-related injuries and illnesses. As is consistent with the community based standard of care, the medical evaluation is primarily based on clinical history, typically absent with testing for fixed or reversible airflow obstruction, airway hypersensitivity, allergic sensitization to occupational and non-occupational allergens and diagnostic workplace challenges (32). While largely absent of diagnostic testing, cases 2 through 8 suggest a clear association of cannabis dust exposure and respiratory symptoms. Cases 5 through 8 had no known history of asthma and their exposures in the industrial cannabis industry preceded the development of symptoms, representing temporality between exposure and disease. The medical history of one cannabis processor (case 7) represents two episodes of shortness of breath upon exposure to cannabis separated by an exposure- and symptom-free interval, strongly suggesting that the symptoms are specific to exposures that occurred while working in cannabis grow operations. Both temporality and specificity support a causal association between cannabis exposure and respiratory symptoms. Further clarifications as to the immunologic or non-immunologic origins of symptoms in relation to cannabis exposure seems necessary. A study by Decuyper et al. observed negative immunological tests in a cohort of police officers with respiratory and/or cutaneous symptoms from occupational cannabis exposure, and concluded that non-immune reactions could be a pathway for the reported symptoms (33). Clinician education as to the hazardous nature of occupational cannabis exposure and the development of cannabis-specific diagnostic tests would help to improve the diagnosis and treatment for cannabis industry workers (14,34). Further research is needed to define the workplace exposures, symptoms, and clinical respiratory disease in these workers.

Two considerations are given when ascribing the occupational exposure of cannabis as the causative agent in cannabis industry workers. The first consideration is for concomitant exposure to other respiratory irritants and sensitizers present in cannabis growing and processing. Endotoxin, fungi and bacteria can put workers at risk for asthma and have been documented at both indoor and outdoor cannabis facilities (35,36). Exposure to mold was found to be a primary health concern for law enforcement teams investigating and dismantling indoor marijuana growing operations, where indoor viable and microscopic

mold spore concentrations were found to be at least 5 times greater than outdoor concentrations in each of 12 indoor marijuana grow operations (37). Additional respiratory irritants in grow operations include chemicals such as ozone, disinfectants, cleaning materials (e.g. bleach), and pesticides (38). Corrosive acids and bases, such as hydrochloric, sulfuric, chromic and acetic acids as well as ammonium hydroxide may be used in the mixing of cannabis plant nutrients (38). A second consideration that complicates the occupational attribution of cannabis-related asthma is personal cannabis consumption and secondhand exposures outside of work. Among the seven cannabis industry workers, (cases 2–8) the histories documented in the medical records reflected a denial of current personal use in four workers and an affirmation of current personal cannabis use in three workers. Personal and social exposures may complicate return-to-work arrangements. Additionally, atopic individuals with occupationally induced *Cannabis* sensitization may experience negative personal and social outcomes if they need to avoid the sensitizer in their social circles.

In addition to identifying emerging exposures such as cannabis, state-based surveillance can identify exposures that affect regional workers and which may not be addressed at the national level. Some of the leading causes of WRA in Washington that have received disease prevention efforts are plant materials, wood dust, and isocyanates. Forest products (trees), secondary wood products, and agriculture are important to the economy of the Pacific Northwest region of the United States and in a continuation of a historical trend, plant material continues to be a leading cause of occupational asthma in Washington State (8). For the historical period 2001–2008, we observed 41 cases of WRA from western red cedar and 36 cases from wood dust; here we report an additional 11 cases for western red cedar and 21 cases for wood dust (8). Historic Washington data prior to 2012 identified 25 respiratory disease cases associated with exposure to the hop plant (*Humulus lupulus*), an agricultural commodity with commercial production centered in this region (39). For the period from 2012 to 2016, an additional 15 cases of WRA from hops were identified, with nine classified as occupational asthma and all associated with hop harvesting and processing activities. Beyond plant material, we previously reported a series of 27 WRA cases from exposure to isocyanates; from 2011 through 2016 an additional seven cases of WRA occurred (40). Hexamethylene diisocyanate (HDI) and methylene diphenyl diisocyanate (MDI) are the leading isocyanates with

exposures occurring predominantly in auto painting, foam applications, tire and cabinet manufacturing. Prevention materials have been developed and disseminated to workers, employers and physicians for each of these relevant regional exposures.

Taking a more general view of the trends identified by the surveillance system, we previously noted a decrease in our WRA surveillance case rates, similar to decreasing trends in the incidence of occupational asthma and allergy reported worldwide (7,41–43). The Health Care and Social Assistance industry sector had the largest proportion of WRA and was skewed predominantly for work aggravated asthma (82%) rather than new onset asthma (9%). The leading exposures for WAA were indoor air pollutants and perfume, as well as cleaning materials, which are known to put healthcare and other workers at risk for asthma (44–47).

The occurrence of new-onset asthma in contrast to WAA signals new cases of preventable occupational disease. NOA with latency arises from exposures that are ongoing over time with some degree of routine occurrence or predictability and as such are ideal environments for prevention interventions such as product substitution or improved industrial hygiene control in the workplace. Four industries with a high proportion of new-onset asthma include Agriculture, Manufacturing, Construction, and Wholesale Trade. NOA in Agriculture and Wholesale Trade is dominated by exposure to plant materials such as hops, followed by chemicals and cleaning materials. In Manufacturing, NOA reflects the regional economy with exposure from wood and cedar dust in sawmills and secondary wood processing, and dust, metal, and chemical exposures in the aerospace industry. NOA in Construction was predominantly caused by exposure to inorganic dust such as silica, miscellaneous chemicals, and epoxies in finishing and equipment contractors. The predominant exposures associated with NOA in these industries are similar to the exposures reported elsewhere for occupational asthma (48–54). Prevention resources directed at these industry sectors with a high prevalence of NOA may be able to reduce the risk of WRA in those populations.

A primary limitation of the surveillance data is case underreporting, which is well-known to occur in occupational disease surveillance and includes the barriers that workers face when wishing to utilize workers' compensation insurance (7,55). Poor clinical recognition of WRA as well as the phenomenon that individuals often do not discuss the association between work and asthma with their doctor, further

contributes to under-recognition of WRA (56,57). Despite the limitation of underreporting, state-based surveillance efforts remain an effective way to identify workers and industries with a high risk of WRA and in need of disease prevention efforts.

Conclusion

Surveillance data indicate that workers across many industry sectors continue to be at risk for work-related asthma. Exposure to agents such as western red cedar, hops, and isocyanates were historically identified as leading causes of WRA and continue to be relevant today. The value of state-based asthma surveillance lies in part in the detection of regional emerging issues, such as the cannabis-associated case series for work-aggravated and occupational asthma that emerged within two years of the legalization of recreational cannabis. Further research is needed to characterize exposure in the cannabis industry, the clinical manifestations of respiratory disease in exposed workers, and effective workplace controls.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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