

Occupational Contact Dermatitis in North American Production Workers Referred for Patch Testing: Retrospective Analysis of Cross-sectional Data From the North American Contact Dermatitis Group 1998 to 2014

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Background: Little is known about the epidemiology of contact dermatitis in production workers (PWs).

Objective: The aims of this study were to estimate the prevalence of contact dermatitis and characterize clinically relevant and occupationally related allergens among North American PWs undergoing patch testing.

Methods: This was a retrospective cross-sectional analysis of North American Contact Dermatitis Group data from 1998 to 2014.

Results: Of 39,332 patch-tested patients, 2732 (7.0%) were PWs. Among PWs, most were men (62.4%) and white (83.9%). A history of childhood eczema was uncommon (11.3%). Prevalent occupations included machine operators (27.3%); fabricators, assemblers, and hand-working occupations (16.8%); and precision metalworking occupations (16.1%). The most frequent sites of dermatitis were the hands (53.8%) and arms (29.4%), which were significantly more commonly affected compared with non-PWs ($P < 0.0001$). Occupationally related skin disease, allergic contact dermatitis, and irritant contact dermatitis were also significantly more common in PWs (49.9% vs 10.6%, 58.9% vs 53.7%, and 32.7% vs 25.7%, respectively; all P s < 0.0001). Epoxy (15.3%), thiuram mix (8.3%), carba mix (8.1%), formaldehyde (6.3%), and cobalt (5.9%) were the most frequent occupationally related allergens. The top allergen sources included adhesives/glues (16.0%), metalworking fluids/cutting oils (6.8%), and coatings (6.3%).

Conclusions: Production workers had a high rate of occupationally related skin disease, as well as irritant and allergic contact dermatitis. Involvement of exposed body areas was common. Frequently identified allergens included adhesives/glues, rubber accelerators, metals, and preservatives.

In the United States, occupational skin diseases and disorders (OSDs) are the top cause of nontrauma work-related illnesses. In a 2014 survey by the US Bureau of Labor and Statistics, OSDs

accounted for 15.2% of all nonfatal occupational illnesses.¹ Occupational skin diseases and disorders are of great importance in Canada as well; the incidence of OSDs in Canadian workers is

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approximately 4.6 cases per 10,000 full-time employees.² Contact dermatitis (CD) is the no. 1 cause of OSDs in the United States and Canada.^{2,3}

In 2015, the US Bureau of Labor and Statistics Current Population Survey documented that there were approximately 8.5 million persons employed in production occupations.⁴ Production workers (PWs) include employees who are involved in the fabrication and assembly of finished products and parts and material handling and supervisors in these industries. Production workers are considered a high-risk group for occupational CD because workers are exposed to many chemicals and materials capable of causing CD.^{5–7} Metal and wood dust generated during production work can induce microtrauma to the skin. In addition, friction from manual labor may damage the skin's barrier function and enhance the penetration of allergens and irritants.⁸

There have been several published studies involving PWs.^{9–13} Suuronen et al¹¹ analyzed 9 years of OSD data in 262 Finnish metalworking machinists and reported an incidence of 1.6 cases of OSDs per 1000 person-years, a 3-fold increased risk of developing an OSD compared with the total working population. This analysis also reported a 3-fold increase in number of new cases of allergic CD (ACD). Gruvberger et al¹⁴ patch tested 163 metalworkers in a Swedish plant that produced automotive engine and driveline components. Occupational dermatoses were diagnosed in 23 (14.1%) of 163 workers. Eleven cases were determined to be ACD, caused by neat oils (4/11), water-based cutting fluids (3/11), and biocides (4/11).

Although there have been previous studies investigating the prevalence of OSDs in PWs, most have analyzed specific occupational subgroups and were conducted outside North America. The purpose of this analysis was to establish the prevalence of occupationally related CD in North American Contact Dermatitis Group (NACDG) member patch-tested North American PWs using 17 years of data from the NACDG. Furthermore, we aimed to characterize responsible allergens, irritants, and occupational sources.

METHODS

NACDG Database

Between July 1, 1998, and December 31, 2014, 39,332 patients were patch tested by the NACDG to a baseline screening series of 50 to 70 allergens. Patch-testing methodology, reaction relevance, and final diagnoses were established according to previously published criteria.¹⁵ Data collected included demographics (age, sex, race), occupation, body sites of dermatitis (up to 3 sites), and patch-testing results. For each positive reaction, clinical relevance, occupational relevance (yes/no), and allergen source were identified. Beginning in 2001, relevant irritants and their occupational relevance were also documented and associated with individual subjects but not specific chemicals. Body site codes and final diagnoses were linked to individual patients but not specific allergens. Clinical relevance for each positive NACDG allergen was coded as

“definite,” “probable,” “possible,” “past,” “unknown,” “not applicable,” or “not tested,” according to published NACDG criteria.¹⁵

Three-digit occupation and industry codes were ascribed to each subject by an occupational classification expert, using the 1990 US Department of Commerce Census Industrial and Occupational Classification Codes.^{15–17} Occupational relevance was determined by occupational exposures and clinical history. Beginning in 1998, a 3-digit source code was assigned to positive reactions on the NACDG standard series, and starting in 2000, a 3-digit source code was also associated with any other (non-NACDG) relevant allergens. All data were manually entered into a computerized database (Access, 2003; Microsoft Corporation, Redmond, WA).

Study Design

Analysis of the deidentified data was approved by the Minneapolis Veterans Administration Medical Center's Subcommittee on Human Studies. For this study, subjects with 3-digit occupation codes included in “Operators, Fabricators, and Laborers” (occupation codes 703–799) according to the 1990 US Department of Commerce Census Industrial and Occupational Classification Codes were initially extracted from the NACDG database.¹⁸ From this group, only subjects with occupations also classified as “Production Occupations” (occupation codes 51-1000 through 51-9197) in the 2010 Standard Occupational Classification System¹⁹ defined by the US Bureau of Labor Statistics were considered PWs and included in the final analyses.

Data Analysis

At a central location, data were manually entered into a computerized database and checked for quality assurance at the time of collection (Access, 2003; Microsoft Corporation). Demographic,

TABLE 1. Production Worker Occupations

Occupational Subgroups	n (%) (N = 2732)
Machine operators, assorted materials	746 (27.3)
Fabricators, assemblers, and handworking occupations	460 (16.8)
Precision metalworking occupations	439 (16.1)
Precision workers, assorted materials	256 (9.4)
Printing machine operators	132 (4.8)
Supervisors, production occupations	123 (4.5)
Machine operators and tenders, except precision metalworking and plastic working machine operators	114 (4.2)
Textile, apparel, and furnishing machine operators	91 (3.3)
Production inspectors, testers, samplers, and weighers	87 (3.2)
Metal and plastic processing machine operators	72 (2.6)
Precision food production occupations	52 (1.9)
Precision textile, apparel, and furnishing machine workers	43 (1.6)
Plant and system operators	39 (1.4)
Precision woodworking occupations	34 (1.2)
Precision inspectors, testers, and related workers	24 (0.8)
Woodworking machine operators	20 (0.7)

final diagnosis, and site of dermatitis data were used to compare PWs with non-PWs with Pearson χ^2 test or Fisher exact test, 2-tailed, SAS 9.2 (Statistical Analysis System; SAS Institute Inc, Cary, NC). $P \leq 0.05$ was considered statistically significant. No adjustments were made for multiple comparisons because of the exploratory nature of this study.

RESULTS

Demographics

Between July 1, 1998, and December 31, 2014, 39,332 patients were patch tested by the NACDG. Of these patch-tested patients, 2732 (7.0%) were PWs, and 36,600 (93.1%) were non-PWs. Overall,

machine operators represented the most frequent occupational subgroups ($n = 1175$ [43.0%]) (Table 1). Production workers were more frequently men ($n = 1705$ [62.4%]) than non-PWs (Table 2). Overall, most PWs were older than 40 years ($n = 1674$ [61.2%]) and white ($n = 2292$ [83.9%]). All atopic markers, as well as a final diagnosis of atopic dermatitis, were significantly less common in PWs as compared with non-PWs. Nearly half of all PWs had dermatitis, which was overall thought to be related to their occupation (1363 [49.9%]); this was significantly higher than non-PWs (10.6%). Involvement of the hands ($n = 1470$ [53.8%]) and arms ($n = 803$ [29.4%]) was significantly more common among PWs, whereas involvement of covered areas (generalized, leg, trunk, anal/genital, and under clothing) was less common. Allergic CD was the most frequent final diagnosis ($n = 1609$

TABLE 2. Characteristics of PWs Referred for Patch Testing

Characteristic	PWs (N = 2732), n (%)	Non-PWs (N = 36,600), n (%)	P	Relative Risk (95% Confidence Limits)
Male	1705 (62.4)	11,769 (32.2)	<0.0001	3.19 (2.96–3.43)
Age > 40 y	1674 (61.2)	24,614 (67.3)	<0.0001	0.79 (0.73–0.85)
White	2292 (83.9)	31,657 (86.5)	0.0001	0.83 (0.75–0.91)
Occupationally related skin disease	1363 (49.9)	3884 (10.6)	<0.0001	6.47 (6.04–6.93)
Atopy				
Hay fever	558 (20.4)	10,388 (28.4)	<0.0001	0.67 (0.61–0.73)
Eczema	310 (11.3)	8086 (22.1)	<0.0001	0.47 (0.42–0.53)
Asthma	302 (11.1)	5411 (14.8)	<0.0001	0.73 (0.65–0.82)
Site*				
Hand	1470 (53.8)	9521 (26.0)	<0.0001	3.00 (2.80–3.23)
Arm	803 (29.4)	5389 (14.7)	<0.0001	2.23 (2.06–2.41)
Face–scalp†	782 (28.6)	9662 (26.4)	0.0111	1.11 (1.02–1.20)
Generalized	447 (16.4)	8030 (21.9)	<0.0001	0.71 (0.65–0.79)
Leg	231 (8.5)	4034 (11.0)	<0.0001	0.76 (0.67–0.87)
Trunk	217 (7.9)	4471 (12.2)	<0.0001	0.64 (0.56–0.73)
Foot	215 (7.9)	2581 (7.1)	0.1086	1.12 (0.98–1.28)
Neck	191 (7.0)	3257 (8.9)	0.0007	0.78 (0.68–0.90)
Most exposed areas	49 (1.8)	616 (1.7)	0.6656	1.06 (0.81–1.40)
Anal/genital	37 (1.4)	1055 (2.9)	<0.0001	0.48 (0.35–0.66)
Other	23 (0.8)	1284 (3.5)	<0.0001	0.25 (0.16–0.37)
Only under clothing	17 (0.6)	564 (1.5)	0.0001	0.42 (0.26–0.67)
Final diagnosis‡				
ACD	1609 (58.9)	19,647 (53.7)	<0.0001	1.22 (1.13–1.31)
ICD	894 (32.7)	9406 (25.7)	<0.0001	1.37 (1.27–1.48)
Other dermatitis	324 (11.9)	5580 (15.2)	0.0001	0.76 (0.68–0.85)
Other dermatoses	209 (7.7)	3615 (9.9)	0.0002	0.77 (0.67–0.88)
Atopic dermatitis	203 (7.4)	5514 (13.9)	<0.0001	0.47 (0.41–0.54)
Psoriasis	107 (3.9)	1558 (4.3)	0.3941	0.92 (0.76–1.11)
Nummular eczema	65 (2.4)	648 (1.8)	0.0214	1.32 (1.04–1.67)
Contact urticaria	45 (1.7)	280 (0.8)	<0.0001	2.01 (1.53–2.64)
Pompholyx	28 (1.0)	277 (0.8)	0.1234	1.33 (0.93–1.89)
Seborrheic dermatitis	26 (1.0)	767 (2.1)	<0.0001	0.47 (0.32–0.68)
Photodermatitis	23 (0.8)	466 (1.3)	0.0497	0.67 (0.45–1.01)
Stasis dermatitis	20 (0.7)	294 (0.8)	0.6866	0.92 (0.60–1.40)

*Total percentage may exceed 100% because up to 3 sites could be identified for each patient.

†Including the face, lips, nose, eyelids, eyes, ears, and scalp.

‡Listed as 1 of 3 final diagnoses; therefore, total percentage may exceed 100%.

TABLE 3. Clinically Relevant and Occupationally Related NACDG Screening Allergens and Their Sources

Allergen	Top Sources (No. Reactions)					Total Reactions (N = 832)
	#1	#2	#3	#4	#5	
Epoxy/bisphenol A	Adhesives (79)	Epoxy resins (20)	Coatings (19)	Coatings, adhesives, dyes, inks, photographic and copying chemicals (3)	Fiberglass insulation (2)	127
Thiuram mix	Gloves (50)	Safety equipment (5)	Machinery/vehicles (5)	Building and construction materials, tools, equipment, and supplies n.o.s. (3)	Miscellaneous chemical mixtures (2)	69
Carba mix	Gloves (49)	Safety equipment (5)	Shoes (2)	Hats, caps, and apparel n.o.s. (2)	Cosmetics, skin, and health care products (2)	67
Formaldehyde 1%	Solvent, oils, lubricants, fuels (27)	Coatings, adhesives (8)	PCPs (7)	Miscellaneous chemicals (4)	Clothing (2)	52
Cobalt	Machinery/vehicles (15)	Metallic elements/dusts, powders, fumes (11)	Coatings, adhesives (5)	Solvent, oils, lubricants, fuels (5)	Tools (4)	49
Potassium dichromate	Coatings, adhesives (8)	Machinery/vehicles (6)	Cement (6)	Solvent, oils, lubricants, fuels (6)	Metallic elements, dusts, powders (4)	42
Nickel	Machinery/vehicles (15)	Metallic elements/dusts, powders, fumes (8)	Tools (4)	Equipment, instruments (3)	Metallic ores (2)	39
2-HEMA*	Adhesives, coatings, inks (17)	Dental prostheses (5)	Acrylic resins (4)	Dentistry materials and products (1)	Solvents, oils, lubricants, fuels (1)	28
MBT	Gloves (16)	Chemicals and chemical products (3)	Building and construction materials, tools, equipment, supplies (1)	Fasteners, ropes, ties (1)	Material handling machinery (1)	25
Quaternium-15	Metalworking fluid (7)	Moisturizers (7)	PCPs other than moisturizers (6)	Adhesives, coatings, inks (3)	Lubricating oils and greases (1)	25
Ethyl acrylate	Adhesives, coatings, inks (13)	Acrylic resins (5)	Dental prostheses (4)	Amalgams and fillings (1)	Solvents, oils, lubricants, fuels (1)	24
Methyl methacrylate	Adhesives, coatings, inks (9)	Dental prostheses (6)	Acrylic resins (3)	Solvents, oils, lubricants, fuels (2)	Amalgams and fillings (1)	21
Mercapto mix	Gloves (10)	Vehicles (2)	Miscellaneous chemical mixtures (2)	Safety equipment (1)	Hats, caps, safety helmets (1)	18
Ethylenediamine dihydrochloride	Adhesives/coatings (9)	Solvents, oils, lubricants, fuels (4)	Miscellaneous chemical products (21)	Epoxy resins (1)	N/A	16
Colophony	Adhesives, coatings, inks (5)	Solvents, oils, lubricants, fuels (2)	Wood, lumbar (2)	Newspapers, books, magazines (1)	Trees and logs (1)	15
Methylchloroisothiazolinone/methylisothiazolinone	PCPs (5)	Coatings (2)	Metalworking fluid, cutting oils (2)	Solvents, oils, lubricants, fuels (2)	Pesticides, horticultural and agricultural chemicals (1)	14

Bisphenol F†	Adhesives (7)	Epoxy resins (4)	Coatings (1)	Gloves (1)	N/A	13
Black rubber mix‡	Machinery/vehicles (8)	Building and construction materials, tools, equipment, and supplies n.o.s. (2)	Safety equipment (1)	Equipment, instruments (1)	Gloves (1)	13
Cocamide DEA†	Solvents, oils, lubricants, fuels (6)	Metalworking fluid, cutting oils (2)	PCPs (2)	Nonskin soaps, detergents (1)	Field crops other than grain (1)	12
Glutaral	Disinfectants (3)	Personal hygiene soaps and cleansers (2)	Dentistry materials and products (2)	Wipes (1)	Chemicals (2)	11

Top 5 sources of NACDG occupationally related allergens with more than 10 occupationally related reactions. Only the top 5 sources of these allergens are included in the table.

*Tested in only 4 cycles (denominator 18,430).

†Tested in only 3 cycles (denominator 14,687).

‡Tested in only 7 cycles (denominator 32,945).

N/A indicates not applicable; n.o.s., not otherwise specified; PCPs, personal care products.

[58.9%]), followed by irritant CD (ICD) (n = 894 [32.7%]) and other dermatitis (n = 324 [11.9%]). Allergic CD and ICD were significantly more frequent in PWs as compared with non-PWs.

Frequencies of Occupationally Related NACDG Allergens

Frequencies of the most common occupationally related NACDG allergens and their sources are summarized in Table 3. Epoxy/bisphenol A (n = 127), thiuram mix (n = 69), carba mix (n = 67), formaldehyde 1% (n = 52), and cobalt (n = 49) were the most common occupationally related allergens in PWs. Figure 1 depicts airborne ACD to epoxy in an assembly line worker.

NACDG Allergen Sources

The sources of occupationally related NACDG allergens are summarized in Table 4. Overall, chemicals and chemical products were the top sources of allergens for PWs. Adhesives, glues, and bonding agents (n = 133); metalworking fluids and cutting oils (n = 56); and coatings (n = 52) were the most common chemical sources of allergens in PWs. Not surprisingly, gloves (n = 142) were also a frequent source of occupationally related allergens.



Figure 1. Photograph depicting a factory assembly line worker with airborne ACD to epoxy (top) and day 5 patch-test results depicting a strong (2+) reaction to epoxy (bottom).

TABLE 4. Occupationally Related Sources of NACDG Allergens

Source	Top Antigens (No. Reactions)			Total (N = 832)
	#1	#2	#3	
Chemicals and chemical products				
Adhesives, glues, bonding agents	Epoxy (79)	HEMA (11)	Bisphenol F epoxy resin (7)	133
Metalworking fluids, cutting oils	Formaldehyde 1% (18)	Quaternium-15 (7)	Cobalt (3), diazolidinyl urea (3)	56
Coatings (paint, lacquer, shellac, varnish, stains)	Epoxy (19)	Potassium dichromate (6)	Formaldehyde 1% (3), EA (3), HEMA (3), ethylenediamine (3)	52
Solvents, oils, lubricants, fuels n.o.s.	Formaldehyde 1% (8)	Cocamide DEA (6)	Potassium dichromate (3)	39
Epoxy resins	Epoxy (20)	Bisphenol F (4)	Ethylenediamine (1)	25
Metallic elements, dusts, powders, fumes	Cobalt (11)	Nickel (8)	Potassium dichromate (4)	23
Coatings, adhesives, dyes, inks, photographic and copy chemicals n.o.s.	Epoxy (3)	EA (2)	Formaldehyde 1% (2)	15
Inks	Cobalt (3)	EA (3)	HEMA (3)	13
Acrylic resins	EA (5)	HEMA (4)	Methyl methacrylate (3)	12
Chemical mixtures*	Thiuram mix (2)	Mercaptobenzothiazole (2)	Mercapto mix (2)	11
Automotive oils and fluids	Formaldehyde (2)	Ethylenediamine (1), MCI/MI (1), MI (1), IPBC (1)	N/A	6
Lubricating oils/greases	Formaldehyde (1), quaternium-15 (1), cobalt (1), mixed dialkyl (1), thioureas (21), potassium dichromate (1), propylene glycol (1)	N/A	N/A	6
Pesticides, horticultural and agricultural chemicals	Formaldehyde (1), Quaternium-15 (1), imidazolidinyl urea (1), DMDM hydantoin (1), MCI/MI (1)	N/A	N/A	5
Formaldehyde resins	Formaldehyde (2)	<i>p</i> -tert-Butylphenol formaldehyde resin (2)	N/A	4
Solvents, degreasers, petroleum distillates	Ethylenediamine (2)	Propylene glycol (1)	N/A	3
Other chemicals	PG (1)	Ethylenediamine (1)	Cobalt (1)	3
Phenolic resins	Formaldehyde (2)	N/A	N/A	2
Industrial dyes and coloring agents	Methyl methacrylate (1)	N/A	N/A	1
Clothing				
Gloves	Thiuram (50)	Carba mix (49)	Mercaptobenzothiazole (16)	142
Other clothing	Carba mix (4)	Thiuram (2)	Potassium dichromate (2), <i>p</i> -phenylenediamine (2)	20
Safety equipment	Thiuram (5)	Carba mix (5)	Cobalt (1), nickel (1), potassium dichromate (1), mercaptobenzothiazole (1), mercapto mix (1), black rubber mix (1), <i>p</i> -tert-butylphenol (21), formaldehyde resin (1)	17

TABLE 5. Clinical Relevance of Top Occupationally Related NACDG Allergens (All Allergens With ≥ 10 Reactions)

Allergen	Clinical Relevance				Total N	% of Total Occupationally Related Positives (N = 1056)
	Definite, n (%)	Probable, n (%)	Possible, n (%)	Past, n (%)		
Epoxy resin 1% pet + bisphenol A 0.1% pet	55 (31.6)	99 (56.9)	18 (10.3)	2 (1.1)	174	16.5
Carba mix 3% pet	10 (12.8)	28 (35.9)	36 (46.2)	4 (5.1)	78	7.3
Thiuram mix 1% pet	7 (9.7)	31 (43.1)	31 (43.1)	3 (4.2)	72	6.8
Nickel sulfate 2.5% pet	7 (10.6)	43 (65.2)	14 (21.2)	2 (3.0)	66	6.3
Formaldehyde 1% aq	3 (4.6)	24 (36.9)	38 (58.5)	0 (0.0)	65	6.2
Cobalt chloride 1% pet	2 (3.2)	29 (46.0)	30 (47.6)	2 (3.2)	63	6.0
Potassium dichromate 0.25% pet	8 (13.6)	28 (47.5)	20 (33.9)	3 (5.1)	59	5.6
Mercaptobenzothiazole 1% pet	4 (12.5)	12 (37.5)	15 (46.9)	1 (3.1)	32	3.0
Ethyl acrylate 0.1% pet	5 (16.1)	12 (38.7)	13 (41.9)	1 (3.2)	31	3.0
Quaternium-15 2% pet	4 (13.8)	13 (44.8)	12 (41.4)	0 (0.0)	29	2.8
2-HEMA 2.0% pet	1 (3.6)	15 (53.6)	11 (39.3)	1 (3.6)	28	2.7
Methyl methacrylate 2% pet	6 (21.4)	17 (60.7)	4 (14.3)	1 (3.6)	28	2.7
Mercapto mix 1% pet	4 (17.4)	5 (21.7)	14 (60.9)	0 (0.0)	23	2.2
Colophony 20% pet	1 (5.3)	11 (57.9)	6 (31.6)	1 (5.3)	19	1.8
Balsam of Peru 25% pet	2 (10.5)	10 (52.6)	7 (36.8)	0 (0.0)	19	1.8
Methylchloroisothiazolinone/methylisothiazolinone 100 ppm aq	1 (5.3)	15 (78.9)	2 (10.5)	1 (5.3)	19	1.8
Ethylenediamine dihydrochloride 1% pet	1 (5.6)	8 (42.1)	9 (50.0)	0 (0.0)	18	1.7
Neomycin sulfate 20% pet	2 (12.5)	12 (75.0)	0 (0.0)	2 (12.5)	16	1.5
Black rubber mix 0.6% pet	4 (30.8)	2 (15.4)	7 (53.8)	0 (0.0)	13	1.2
Methyldibromo glutaronitrile/phenoxyethanol 2.0% pet	0 (0.0)	6 (46.2)	7 (53.8)	0 (0.0)	13	1.2
Bisphenol F 1% pet	3 (23.1)	7 (53.8)	3 (23.1)	0 (0.0)	13	1.2
Glutaral 1% pet	0 (0.0)	6 (46.2)	5 (45.5)	0 (0.0)	11	1.0
p-Phenylenediamine 1% pet	0 (0.0)	2 (18.2)	7 (63.6)	2 (18.2)	11	1.0
Cocamide DEA 0.5% pet	0 (0.0)	8 (72.7)	3 (27.3)	0 (0.0)	11	1.0
Fragrance mix 8% pet	1 (10.0)	4 (40.0)	4 (40.0)	0 (0.0)	10	1.0
Total*	144 (13.6)	504 (47.7)	375 (35.5)	29 (2.7)	1056	100.0

Past and unknown clinical relevancies were also recorded.

*Totals include all occupationally related positive reactions.

Definite relevance indicates positive use- or patch-test reaction to a putative item containing the allergen in question; probable relevance, presence of allergen in the known skin contacts of the patient; possible relevance, exposure to circumstances in which skin contact with materials known to contain a given allergen was likely.

than non-PWs. Occupationally related skin disease and a final diagnosis of ACD and ICD were all more common in PWs. Adhesives and glues, rubber accelerators, metals, and preservatives were the most commonly observed occupationally related allergens. Chemicals were the no. 1 source of occupationally related ACD and ICD in PWs. Irritant CD was diagnosed in approximately one third of PWs; metalworking fluids, cutting oils and solvents, degreasers, and petroleum distillates were the most frequently identified irritant sources.

Demographics, Occupational Relevance, Final Diagnosis, and Site of Dermatitis

The higher proportion of PWs who were older than 40 years (61.2%) and men (62.4%) is likely reflective of existing sex differences in the US labor force among PWs. In 2015, the average age of all US PWs

was 42.9 years.²⁰ In 2015, the US Bureau of Labor and Statistics Current Population Survey documented that approximately 78.2% of PWs were men,²¹ although this varied somewhat, depending on specific PW occupation. Women outnumbered men in electrical and electromechanical assemblers, sewing machine operators, tailors, dressmakers, and laundry and dry-cleaning workers.²¹

Occupational skin diseases and disorders were significantly more common in PWs as compared with non-PWs. We found that nearly half (49.9%) of PWs had OSD. This is somewhat expected and consistent with the prediction that PWs are at a high risk of developing CD because of friction from industrial machines and tools and exposures to a variety of irritants and allergens including adhesives, rubber chemicals, metals, and preservatives. A final diagnosis of ACD and/or ICD was significantly more common in the PW group. Allergic CD (58.9%) was more common than ICD (32.7%); this value for ICD likely underestimates the prevalence, as

TABLE 6. Top Non–Occupationally Related Allergens With Clinical Relevance*

Allergen	Clinical Relevance					Total	% of Total Non–Occupationally Related Positives (N = 3192)
	Definite, n (%)	Probable, n (%)	Possible, n (%)	Past, n (%)	Unknown, n (%)		
Nickel sulfate 2.5% pet	1 (0.4)	39 (14.0)	82 (29.5)	106 (38.1)	50 (18.0)	278	8.7
Neomycin sulfate 20% pet	10 (4.0)	27 (10.8)	43 (17.1)	93 (37.1)	78 (31.1)	251	7.9
Bacitracin 20% pet	15 (7.2)	28 (13.5)	44 (21.2)	68 (13.5)	53 (25.5)	208	6.5
Balsam of Peru 25% pet	2 (1.0)	30 (15.2)	99 (50.3)	10 (5.1)	56 (28.4)	197	6.2
Fragrance mix 8% pet	3 (1.9)	30 (18.8)	87 (54.4)	10 (6.3)	30 (18.8)	160	5.0
Quaternium-15 2% pet	3 (2.2)	33 (23.9)	74 (53.6)	4 (2.9)	24 (17.4)	138	4.3
Cobalt chloride 1% Pet	0 (0.0)	8 (7.0)	35 (30.4)	30 (26.1)	42 (36.5)	115	3.6
Formaldehyde 1% aq	0 (0.0)	23 (20.2)	56 (49.1)	4 (3.5)	31 (27.2)	114	3.6
Methyldibromo glutaronitrile/phenoxyethanol 2.0% pet	0 (0.0)	17 (16.8)	44 (43.6)	4 (4.0)	36 (35.6)	101	3.2
Sodium gold thiosulfate 0.5% pet	1 (1.1)	4 (4.3)	20 (21.3)	7 (7.4)	62 (66.0)	94	2.9
p-Phenylenediamine 1% pet	2 (2.3)	21 (23.9)	10 (11.4)	18 (20.5)	37 (42.0)	88	2.7
Thimerosal 0.1% pet	0 (0.0)	0 (0.0)	2 (2.5)	20 (25.3)	57 (72.2)	79	2.5
Carba mix 3% pet	0 (0.0)	11 (19.0)	19 (32.8)	6 (10.3)	22 (38.0)	58	1.8
Potassium dichromate 0.25% pet	1 (1.8)	7 (12.3)	17 (29.8)	4 (7.0)	28 (49.1)	57	1.8
Propylene glycol 30% aq	3 (5.5)	22 (40.0)	19 (34.5)	1 (1.8)	10 (18.2)	55	1.7
Lanolin alcohol 50% pet	6 (11.8)	21 (41.2)	17 (33.3)	2 (3.9)	5 (9.8)	51	1.6
Methylchloroisothiazolinone/methylisothiazolinone 100 ppm aq	1 (2.0)	22 (44.0)	17 (34.0)	0 (0.0)	10 (20.0)	50	1.6

Past and unknown clinical relevancies were also recorded.

*All allergens with 50 or more reactions.

Definite relevance indicates positive use- or patch-test reaction to a putative item containing the allergen in question; probable relevance, presence of allergen in the known skin contacts of the patient; possible relevance, exposure to circumstances in which skin contact with materials known to contain a given allergen was likely.

the study population was referred for patch testing because of suspicion of having ACD.

Involvement of the hands and arms was significantly more frequent in PWs as compared with non-PWs, although spread to covered body sites is not uncommon in occupational settings. In PWs, the hands (53.8%) were the most frequent body site, followed by the arms (29.4%). This is particularly salient because chronic hand dermatitis has been shown to significantly reduce quality of life and is associated with marked functional impairment.²²

NACDG Screening Allergens and Their Sources

The top 3 currently relevant and occupationally related NACDG screening allergens in PWs were epoxy, thiuram mix, and carba mix. These common allergens have also been found to be top allergens in studies of select PW occupations. Our study confirmed the allergenicity of these compounds in the workplace, typically from adhesives, coatings, gloves, safety equipment, solvents, oils, lubricants, and machinery.

Adhesives

Epoxy was the no. 1 occupationally related allergen in PWs. Epoxy resin is the reactive and uncured form of epoxy. The most common occupational sources of epoxy were adhesives, epoxy resins, and coatings. Epoxy adhesives are one of many structural adhesives used for the manufacturing of aircrafts, vehicles, skis, hockey sticks, and other goods in which high-strength bonds are required.

In Finland, Aalto-Korte and colleagues²³ examined 209 cases of occupational contact allergy to epoxy chemicals. More than half (n = 109 [52%]) of the patients in this study worked in industrial trades. The most common jobs associated with occupational ACD to epoxy were aircraft production, industrial painting, and manufacturing of electric machines, transformers, and wiring.²³ Jolanki et al²⁴ studied 22 workers in an Estonian ski factory who were suspected of having OSD and were heavily exposed to epoxy resins in the workplace. They found occupational ACD in 8 of 22 patients; 6 cases were caused by epoxy resin compounds.²⁴

Allergic CD to acrylates, including ethyl acrylate, methyl methacrylate, and 2-hydroxyethyl methacrylate (HEMA), was also commonly seen in our study population. Of note, these are the only methacrylates/acrylates included in the NACDG screening series. Occupational sources of acrylates in PW included adhesives, inks, dental prostheses, and dental materials. There were 40 dental laboratory and medical appliance technicians included as PWs in this study. Ethylenediamine dihydrochloride, colophony, and bisphenol F were other adhesive-related chemicals that were frequently positive in PWs.

Rubber Chemicals

The rubber accelerators thiuram mix and carba mix were, respectively, the second and third most common allergens for PWs in this analysis. Gloves were the top source of these allergens. Many PWs wear thin stretchable gloves to allow for manual dexterity. These

TABLE 7. Sources of Occupationally Related Non-NACDG Screening Allergens

Category	n	% of Total (N = 428)
Chemicals and chemical products	335	78.3
Adhesives, glues, bonding agents	153	35.7
Metalworking fluids, cutting oils	53	12.4
Coatings (paint, lacquer, shellac, varnish, stains)	27	6.3
Solvents, oils, lubricants, fuels	16	3.7
Inks	15	3.5
Lubricating oils/greases	9	2.1
Acrylic resins	8	1.9
Phenolic resins	8	1.9
Chemical mixtures*	8	1.9
Epoxy resins	6	1.4
Photographic chemicals	5	1.2
Solvents, degreasers, petroleum distillates	5	1.2
Urethane resins	4	0.9
Industrial dyes and coloring agents	4	0.9
Formaldehyde resins	2	0.5
Other	12	2.8
Clothing	22	5.1
Gloves	9	2.1
Safety equipment	3	0.7
Other clothing	10	2.3
Building and construction materials, tools, equipment, supplies	16	3.7
Building materials	8	1.9
Sealants, caulking and insulating materials	6	1.4
Other	2	0.5
Personal care products	15	3.5
Biologic materials	12	2.8
Machinery/vehicles	8	1.9
Medications	6	1.4
Soaps (nonskin)	3	0.7
Other	11	2.6

*Other than acrylic, epoxy, urethane, phenolic, formaldehyde, and polyvinyl chloride.

types of gloves are often made from natural rubber latex or synthetic nitrile rubber. Production of these gloves requires vulcanizing agents (accelerators). Trace amounts of residual accelerators, such as thiurams, dithiocarbamates, and mercaptobenzothiazole, are often released during glove use and responsible for associated ACD.¹³ Geier et al¹³ published an analysis of 3448 patients with occupational dermatitis with suspected ACD to gloves patch tested in Germany, Switzerland, and Austria. Mechanics, machinists, and toolmakers comprised 7.3% (n = 253) of the study population. Similar to our results, Geier et al¹³ reported that thiurams (13.0%) were the most frequent cause of occupational ACD to rubber gloves, followed by dithiocarbamates (3.5%). Safety equipment and machinery were also common sources of ACD to these rubber accelerators.

Preservatives

Preservatives were common sources of occupational allergy in PWs. Formaldehyde is a preservative with antimicrobial properties

and is used as a biocide in many metalworking fluids and cutting oils. In a Finnish study of 81 patch-tested patients with formaldehyde allergy, metalworkers comprised the greatest proportion (40%) of new occupational sensitizations to formaldehyde.¹² Although in recent years some manufacturers have replaced formaldehyde with other preservatives in personal care products, our analysis suggests that this chemical is used in many industrial products.²⁵ In a study of 107 Finnish metalworking machinists, formaldehyde and unspecified formaldehyde-releasing chemicals were determined to be the top ACD culprits (23/107 [21.5%]), which was primarily attributed to exposure from metalworking fluids.¹¹ Common occupational sources of formaldehyde in our study population included solvents, oils, and lubricants, followed by coatings and adhesives, and personal care products.

Metals

Cobalt, potassium dichromate, and nickel are metals that were common causes of ACD in PWs. Cobalt is frequently used as an alloy in steel that requires strength and durability. Coatings, paints, and adhesives may contain cobalt or other metals to hasten the drying process. Given these properties, it is not surprising that exposure sources included machinery, vehicles, industrial tools, coatings, and adhesives. There are reports of metallic dust causing ACD in workers producing alloys of cobalt.²⁶ In Sweden, Fischer and Rystedt²⁷ reported that hard metals contain approximately 10% cobalt. They patch tested 853 hard-metal workers and noted positive reactions to 1% cobalt chloride in 62 workers. Jobs that involved hand etching and grinding were associated with damage to the skin barrier and were a risk factor for cobalt sensitization. Several studies have analyzed contact allergens in tools. In 1 Swedish study, 27% of the 565 handheld tools with metal parts that came in contact with the skin were found to contain nickel (dimethylglyoxime test positive).²⁸ More recently, 600 handheld tools from the German market were investigated for nickel and



Figure 2. Photograph depicting a machinist's hands with severe ICD.

TABLE 8. Sources of Occupationally Related Irritants in PWs

Source	All PWs	
	n	% of Total (N = 610)
Chemicals and chemical products	413	67.7
Metalworking fluids, cutting oils	106	17.4
Solvents, degreasers, petroleum distillates	68	11.1
Adhesives, glues, bonding agents	61	10.0
Solvents, oils, lubricants, fuels	27	4.4
Chemical mixtures*	22	3.6
Metallic elements, dusts, powders, fumes	22	3.6
Lubricating oils and greases	21	3.4
Coatings (paint, lacquer, shellac, varnish, stains)	16	2.6
Inks	13	2.1
Acids, alkalis, hydrocarbons	10	1.6
Acrylic resins	6	1.0
Epoxy resins	5	0.8
Urethane resins	4	0.7
Photographic chemicals	3	0.5
Phenolic resins	2	0.3
Industrial dyes and coloring agents	2	0.3
Formaldehyde resins	2	0.3
Other	23	3.8
Clothing, textiles	30	4.9
Gloves	7	1.1
Textiles	6	1.0
Safety equipment	2	0.3
Other	15	2.5
Building and construction materials, tools, equipment, supplies	38	6.2
Building materials	14	2.3
Fiberglass	10	1.6
Other	14	2.3
Personal care products	17	2.8
Plants and minerals	27	4.4
Food products	11	1.8
Metal ores	10	1.6
Plants	3	0.5
Rocks, stone, sand, gravel	3	0.5
Machinery/vehicles	17	2.8
Soaps, detergents (nonskin)	30	4.9
Other	38	6.2

*Other than acrylic, epoxy, urethane, phenolic, formaldehyde, and polyvinyl chloride.

cobalt release. Nickel release was detected in 195 tools (32.5%), and cobalt release was detected in only 6 (1%) of the tools.²⁹

Sources of Occupationally Related Non-NACDG Allergens

There were 428 occupationally related non-NACDG allergen sources identified in the study population. Chemicals and chemical products (n = 335) were the most frequent sources of non-NACDG occupationally related allergens. This figure underscores the need

to patch test with supplemental allergens beyond a screening series such as the NACDG series (70 allergens) or the more limited TRUE Test (35 allergens).

Irritants

In our analysis, 32.7% of patch-tested PWs ultimately received a diagnosis of ICD. Of the irritant sources recorded in this study, metalworking fluids, cutting oils, solvents, degreasers, petroleum distillates, adhesives, and glues were the most commonly identified. These findings align with previous studies showing metalworking fluids, oils, lubricants, and solvent as the top sources of occupational ICD in PWs.¹¹

Limitations

There are several limitations of this study. As a cross-sectional descriptive study, definitive causal relationship cannot be determined. Large prospective studies are needed to comprehensively understand the development of ACD in PWs. The patients included in this analysis represent a referral population suspected of having ACD. As such, our results may not be generalizable to other populations of PWs. The designation of source was limited by the knowledge of the practitioner and the existing 3-digit source codes. Many occupational allergens are not commercially available. Because of the small sample size, we did not analyze results over time; therefore, trends in allergens (eg, specific biocides used in industry) were not addressed. Finally, the specific names of non-NACDG allergens were not recorded.

CONCLUSIONS

Among individuals patch tested by the members of the NACDG group between 1998 and 2014, being male and having hand dermatitis were commonly reported in PWs. The most common occupationally related and currently relevant allergens were epoxy resin, thiuram mix, carba mix, formaldehyde, and cobalt. Overall, chemicals were the most frequent sources of occupationally related ACD in PWs. Specific allergen sources were not unexpected and included adhesives, glues, bonding agents, metalworking fluids, cutting oils, coatings, machinery, personal care products, and gloves. These findings provide important information for clinicians about the profile of CD among PWs referred for patch testing in North America.

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