Respiratory Symptoms Among Crab Processing Workers in Alaska: Epidemiological and Environmental Assessment

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Background *Crab processing workers may develop respiratory symptoms and specific IgE responses, but the risk factors have not been fully described.*
Methods *In 1998, 107 workers at a crab processing facility completed a survey both at the beginning and end of the processing season. The surveys included standardized symptom questionnaires, spirometry, and serological testing, as well as measurement of workplace airborne crab allergens and microscopic analysis of aerosolized materials.*
Results *Over the crab processing season, asthma-like symptoms developed in 26% of study participants and bronchitic symptoms in 19%. Only 9% of those with new asthma-like symptoms were IgE-sensitized to crab at the end of the season. Among the crab processing jobs, butchering and degilling workers had the highest incidence of respiratory symptoms.*
Conclusions *Both personal and process-related factors appear to affect the development of respiratory symptoms in crab processing workers. In this study, crab specific IgE was not detected in most of the workers with new symptoms.* Am. J. Ind. Med. 39:598–607, 2001. *Published 2001 Wiley-Liss, Inc.*†

KEY WORDS: occupational asthma; bronchitis; crab; IgE; environmental assessment

INTRODUCTION

Asthma and asthma-like symptoms have been identified among crab processing workers, but the incidence, host and occupational risk factors, and course of disease have not yet been fully described. In 1982, the National Institute for Occupational Safety and Health (NIOSH) reported a survey of 46 symptomatic crab processing workers who sought care at a health clinic in Dutch Harbor, Alaska. The investigation concluded that during the crab processing season, the estimated rate of onset of dyspnea with wheeze was 80 times the monthly incidence of asthma for similarly aged Americans [MMWR, 1982]. Snow crab has been implicated in cases of occupational asthma (OA) among processing workers with a reported prevalence of 15.6% [Cartier et al., 1984]. In addition, published reports suggest that asthma in crab processing workers is an IgE-mediated process [Cartier et al., 1986; Malo et al., 1997; Weytjens et al., 1999]. Sensitization to a high molecular weight antigen liberated during the crushing of shells, the boiling of whole crab, and the separation of legs and claws has been demonstrated [Cartier et al., 1986]. Another study in a crab processing facility associated the cooking area with high exposure to crab allergen [Malo et al., 1997]. More recently, a study at a

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crab processing facility showed that the crab cracking section had the highest allergen exposure, suggesting that allergen exposure is associated with job task [Griffin et al., 1994].

Respiratory illness in workers at crab processing plants has imposed a substantial economic burden on this industry in recent seasons [Bishop, 1999]. Consequently, in December 1997, a Health Hazard Evaluation was requested by a shore-based seafood processing facility in Dutch Harbor, Alaska, to evaluate the relationship between workers' respiratory health and workplace exposures over the 1998 opilio snow crab (*Chionoecetes opilio*) season.

The aim of this study was to investigate the factors, including workers' exposures, associated with the development of respiratory symptoms in crab processing workers.

MATERIALS AND METHODS

Process Description

Processing begins with live snow crabs in the holds of ships. The crabs are transported by workers called "unloaders" from the ships to the processing building. "Butchers" separate the leg clusters and the internal organs (kanimiso) from the shell. The internal organs are collected and flash frozen in an adjacent area. The leg clusters are transported via conveyor belt to "degillers" who remove the gills, and are then conveyed to the packing and sorting line. At this station, "packers" sort and pack leg clusters into stainless steel tubs which are sent to the cooking tank where "cookers" immerse the tubs in boiling water for about 15 min. The tubs are transferred to an ambient water tank for rinsing and cooling, transported to a chilled water tank to further reduce their temperature, and then immersed in a brine tank. Finally, "case-up" workers transfer the now frozen crab leg clusters from the tubs to cardboard boxes for shipment to wholesalers.

During the processing season, workers sometimes rotate among the different work stations. Workers in the crab processing plant wear personal protective equipment that includes hard hats, safety glasses, ear plugs, rain suits, and insulated rubber gloves and boots. Nevertheless, they are potentially exposed to aerosolized crab particulate, sea water spray, and cooking steam generated during the butchering, degilling, and cooking processes. Workers in the vicinity of these processes may also be exposed to products released from the crab.

Study Population

A total of 160 crab processing workers were employed to work 12-hour shifts, 7 days a week for nearly 60 days at this processing facility in Dutch Harbor, Alaska. One-hundred and twenty-two participants completed both early-season (23–28 January 1998) and late-season (5–10 March 1998) surveys. The early-season survey began 2 days after the actual crab-processing season started. The late-season survey concluded with the end of the crab-processing season. Completion of the evaluation of all the workers that participated in each of the surveys required approximately 6 days. To be included in the subsequent analysis, a worker must have spent at least 4 weeks in crab processing activities. For the analysis, each worker was assigned to one of the following job categories: unloading, butchering, degilling, packing, case-up, mixed/high exposure, and mixed/low exposure. Butchering, degilling, and cooking jobs were a priori classified as "high exposure" based on observation of aerosol released. To be classified into one of these job categories, each worker had to have spent at least 3 weeks in the job and work longer in that job than in any other job. Workers were categorized as having a mixed job type if they had not spent at least 3 weeks in a single job, or if the number of weeks spent in the two longest jobs was the same. The mixed/high group included workers with at least 3 weeks total in butchering, degilling or cooking. The mixed/low group included workers with less than 3 weeks in butchering, degilling or cooking.

Workers were also divided into 2 groups based on their previous work in the crab industry. Those with 4 weeks or less lifetime experience in the crab industry at the early-season survey were categorized as "naive." The remaining participants were categorized as "experienced" workers. This study was approved by the NIOSH Institutional Review Board to assure ethical treatment of human subjects.

Questionnaire

Trained interviewers administered questions modified from the British Medical Research Council [1966] respiratory questionnaire and the International Union Against Tuberculosis and Lung Disease questionnaire [Burney et al., 1989]. Participants were asked about upper and lower respiratory symptoms, skin symptoms, personal and family health history, work history, work activities, tenure in the crab industry and tobacco use. We defined "asthma-like symptoms" as having at least two of the following: chest ever sounding wheezy or whistling (apart from colds); having attacks of shortness of breath with wheezing or whistling with breathing absolutely normal between attacks; being bothered by tightness in the chest; having been awakened by an attack of coughing, wheezing, or shortness of breath; or having an attack of shortness of breath or coughing that came on during or shortly after stopping exercise. We defined "bronchitic symptoms" as having both a usual cough on most days or nights and usually bringing up phlegm from the chest on getting up, or first thing in the morning.

Spirometry

Spirometry was performed before and after bronchodilator administration using a dry rolling-seal volume spirometer (NIOSH-Ohio modified system) interfaced to a dedicated computer [Hankinson, 1986]. Procedures conformed to standard guidelines [ATS, 1995]. Predicted values were calculated using published reference equations by Knudson et al. [1983]. Abnormal tests (FEV_1, FVC, and FEV_1/FVC) were defined as results below the lowest 5th of the percentile limit of the predicted value (i.e., the lower limit of normal [LLN]). Obstruction was defined as measured ratio of FEV_1/FVC below the LLN. A bronchodilator response was defined as greater than an 8% increase in FEV_1 after administration [Lorber et al., 1978].

Serological Studies

Blood samples were collected by venipuncture for determination of total IgE, specific IgE antibodies, and eosinophil cationic protein (ECP). Serum was obtained by centrifugation of blood samples, frozen, shipped to the NIOSH immunology laboratories and stored at $-80°C$ until analyzed. All samples were tested in duplicate. Atopy was defined as having at least one positive test greater than or equal to Class II to any one of the following aeroallergens: house dust mite mix, mold mix, weed mix, or epidermal mix, using the Pharmacia CAP System (Pharmacia and Upjohn, Kalamazoo, MI). Total IgE and serum ECP levels were determined using the Pharmacia CAP System according to the manufacturer's recommended procedure. Serum levels of ECP ≥ 23 μg/L were considered as positive for an active inflammatory process [De Blay et al., 1998]. Total IgE levels ≥ 100 kU/L were considered elevated [Sunyer et al., 1996].

Crab Specific IgE Antibodies

IgE antibodies to crab were measured using Pharmacia CAP for *Cancer pagurus* crab (a score equal to or greater than Class II was considered positive). RAST assays were also developed for the detection of specific IgE antibodies to snow crab extracts (the species processed in this plant). Briefly, allergen extracts were prepared from four types of bulk samples collected at the plant (cooking water, uncooked crab meat, cooked crab meat, and kanimiso). The cooking water was clarified by centrifugation and filtration (0.45 micron porosity), dialyzed against carbonate coupling buffer and concentrated by ultrafiltration (Amicon YM-2 membrane). The crab meat extracts were prepared by suspending finely minced samples in 0.05 M ammonium bicarbonate buffer (10% W/V) for 18 h at 4°C, followed by centrifugation, filtration and dialysis as above. The kanimiso samples were initially centrifuged at a low speed (500 g) to remove particulate matter, followed by high speed centrifugation (10,000 g for 2 h) to separate lipid material. The aqueous phase material was processed as above. All extracts were coupled to cyanogen-bromide activated sepharose beads according to the manufacturer's recommended procedure (Pharmacia). A RAST assay was developed for each extract using I^{125} labeled anti-human IgE (Diagnostic Products Corporation, Los Angeles, CA). Optimal concentrations of the solid phase reagents were determined and a known pool of sera with IgE to snow crab (provided by Dr. Samuel Lehrer, Tulane University) was used as a positive control to evaluate the allergen preparations. Results were expressed as a RAST score determined by dividing the counts bound to allergen-coated beads by counts bound to human serum albumin (HSA)-coated beads. Positive tests were defined as a score equal to or greater than the 90th percentile among all "naive" workers in the early-season survey. RAST assays performed using extracts derived from cooking water, uncooked meat and cooked meat gave nearly identical results, so only the crab meat and kanimiso allergen results are presented here.

Worker Crab Allergen Exposure

Personal air samples for measurement of airborne crab allergen during the early-season survey were collected on 37-mm glass fiber filters and sampled at a flow rate of 2.0 L/min for 8 h. The flow rate for the late-season survey was increased to 4.0 L/min to improve yield of detectable samples. Filters were extracted with distilled water, and the allergen content of the extracts was determined by RAST-inhibition. The selected allergen extracts (crab meat and kanimiso) collected during the initial survey were defined as containing 1,000 relative allergen units (RAU) per milliliter, and serial dilutions were prepared to construct a standard curve for each inhibition assay. The sera used for the inhibition studies were selected on the basis of the IgE results from the participants. The anti-crab meat pool contained sera that reacted strongly with the meat allergens ($>10\%$ counts bound) but weakly or not at all with the kanimiso extract; the anti-kanimiso sera reacted strongly with the kanimiso allergen but weakly or not at all with the crab meat extract. The limits of detection were found to be approximately 1 RAU/ml for the crab meat assay and 5 RAU/ml for the kanimiso assay.

Microscopic Analysis

Air samples were collected for microscopic analysis by drawing air at a flow rate of 2.0 L/min through polycarbonate filters. An open face cassette was used to help insure an even density of particles across the filter. Settled dust sampling was conducted by placing glass microscope slides at various points throughout the facility.

The surfaces of safety glasses worn in various areas were also examined. Surface and filter samples were first examined with a stereomicroscope, followed by light and scanning electron microscopy.

Statistical Analysis

The health outcome data were examined cross-sectionally at the early and late-season surveys and longitudinally by examining the changes over time. Longitudinal changes were evaluated using McNemar's test. Cross-sectional analyses were performed with Mantel–Haenszel χ^2 test using Epi Info version 6.04b (CDC, Atlanta, GA). Descriptive statistics and tables were produced with JMP Start Statistics (SAS Institute Inc. Cary, NC). A *P* value ≤ 0.05 was considered statistically significant. Any relative risk (RR) higher than 1.0 was considered to be statistically significant if the lower bound of the 95% confidence interval (CI) for the estimate was ≥ 1.0. A continuity corrected estimate was used for those cells in a 2×2 table with zero value. A relative risk higher than 1.5, but whose 95% CI lower bound included 1.0, suggested an association or trend without reaching statistical significance.

RESULTS

Demographics and Personal Profile

During the early-season survey, 152 (95%) of the eligible workers ($n = 160$) completed the questionnaire. Seventy-six percent of the eligible workers (122/160) completed both the early-and late-season surveys. Of these 122, fifteen were excluded from further analysis because they had not spent at least 4 weeks in crab processing. Of these, 9 workers were interviewed by telephone. One of them left for a respiratory problem (asthma); all others left for non-respiratory causes. Thirty workers were excluded from the final analysis because they only completed the early-season survey. Of the remaining 107 workers, 78% were males, 59% were non-whites, and the average age was 36 years (range 18–63). Fifty-one percent of the workers had worked previously in the crab industry, with a median tenure of 5 months. Forty-eight percent of the workers had never smoked cigarettes, and 35% were current smokers. A family history of allergies was present in 21% of the workers (Table I).

Respiratory Symptoms

Table II shows prevalence and incidence of individual symptoms, asthma-like symptom complex, and bronchitic symptoms at each cross-sectional survey and over the season. A significant change in prevalence of the asthma-like symptom complex was observed over the season (14% at the early-season vs. 32% at the late-season). Similarly, a statistically significant increase in prevalence of bronchitic symptoms was observed among the crab workers (2% at the early-season vs. 21% at the late-season survey).

Asthma-like symptoms. In this group of crab processing workers, 86% (92/107) were at risk for development of new asthma-like symptoms. In univariate analysis for associated factors, a statistically significant association with family history of allergies and elevated serum ECP (Table III) wasfound. A trend for the development of asthma-like symptoms was also noted in association with age less than 35 years, smoking, naive tenure status, serum specific IgE antibodies to kanimiso and *C. pagurus* crab; however these associations did not attain statistical significance. The unloading workers (working outside the plant) did not develop asthma-like symptoms and were used as a referent group for the analysis of job categories. Forty percent of butchering workers and 36% of degilling workers had the highest incident rates of asthma-like symptoms.

Bronchitic symptoms. Ninety-eight percent of the crab processing workers (105/107) were at risk for development of new cough and phlegm over the season. The univariate analysis of factors associated with these symptoms showed significant associations with age less than 35 years, elevated serum anti-kanimiso IgE, elevated serum anti-*C. pagurus* IgE and elevated serum ECP (Table III). Trends toward increased bronchitic symptoms were observed for male gender, smoking, atopy, family history of allergies, naive tenure status, and ''high exposure jobs''. Similar to the asthma-like symptom complex, the job categories with the highest percent of workers with incident symptoms were butchering and degilling (25 and 38% respectively).

Spirometry Findings

Spirometry results from both the early and late season surveys were available in 85% (91/107) of the subjects. Serial peak flow monitoring was not possible due to the nature of the work shift; 12-hour days, 7 days a week for 60 days. Pulmonary function was similar at the beginning and end of the crab season. Overall, 4% (4/91) of the participants at the late-season survey met the definition for obstructive pattern. A change of $> 8\%$ (post-bronchodilator) in FEV_1 was observed in 10 of the workers at the end of the season; of those, 8 were of new onset by the late season. All eight workers with new bronchodilator responses had a family history of allergies. Atopy was present in three of these workers, and specific IgE antibodies to both crab *C. pagurus* and to kanimiso were present in two workers. Four of these workers were current smokers. All worked in jobs inside the plant. Four developed bronchitic symptoms and two developed asthma-like symptoms.

TABLE I. Demographic and Personal Characteristics of Crab Processing Workers in Alaska, 1998

Characteristics	Completed early and late surveys (n = 107)	Completed early and late surveys but excluded[a] (n = 15)	Completed only early survey (n = 30)
Age, years ± SE	36 ± 1	40 ± 3	35 ± 2
Percent gender			
Males	78	46	83
Females	22	54	17
Percent race	c		
Whites	41	53	37
Asian/ Pacific Islander	37	7	10
Blacks[e]	15	40	40
American Indians	5	0	0
Other	2	0	13
Tenure status			
Percent experienced[b]	51	40	37
Median months of experience (25–75th percentiles)	5 (2–8)	3 (1–6)	3 (0–5)
Percent smoking status		c	c
Never smoker	48	64	60
Current smoker	35	29	11
Former smoker	17	7	29
Percent family history of allergies	21	33	30
Percent Total IgE > 100 IU/ml	42	27	36
Percent atopy[d]	45	40	42

[a]Excluded because worked less than 4 weeks in crab processing.
[b]Experienced workers were those with more than 4 weeks of work in the crab industry at the early season.
[c]Missing data.
[d]Atopy was defined as a positive serological test to one or more common allergens at the early season.
[e]20% African American, 80% African (Somalia).

IgE Antibodies

Serum levels of total and crab-specific IgE antibodies were determined in both the early and late season surveys for 90% (96/107) of the participating crab processors. The median levels of total IgE were 74 kU/L at the late season. Levels of crab-specific IgE antibodies were higher among "naive" workers. Twelve percent of such workers had positive levels of IgE to kanimiso and crab meat at the end of the season. In contrast, only 2% of the experienced workers had positive levels to kanimiso and none to crab meat extracts at the end of the season (Table IV). The percent of specific IgE antibodies measured using the Pharmacia CAP for crab *C. pagurus* was similar among naive and experienced workers (10 and 11%, respectively). No significant changes were observed in the percent of IgE reactivity over the crab processing season. Overall, few of the workers with either asthma-like symptoms or bronchitic symptoms (9 and 21%, respectively) had elevated IgE levels to kanimiso measured at the end of the season.

Personal Air Samples and Crab Allergen Determination

During the early-season survey, 43 personal samples were collected for allergen determination. The crab meat allergen was only detected on 8 (19%) of the samples, and kanimiso allergen was detected on 26 (60%) of the samples. From a total of 29 personal air samples collected over the late-season survey, 5 (17%) detected crab meat allergen, and 24 (82%) detected kanimiso allergen (data not shown). Although statistically significant differences in exposure levels to kanimiso or crab-meat were not demonstrated between the various job categories, the highest individual measurements were collected among degilling, butchering, and case-up employees.

TABLE II. Percent Prevalence and Incidence of Symptoms of Crab Processing Workers in Alaska, 1998

Symptoms	Percent prevalence early-season (n = 107)	Percent prevalence late-season (n = 107)	Percent incidence (New onset)
Asthma-like symptoms	14	32[c]	26
Chest ever sound wheezy or whistling apart from colds or on most days each week	10	17	11
Attacks of SOB with wheezing with normal breathing between attacks	7	14	13
Tightness in chest	8[a]	22[bc]	19
Awakened by an attack of cough, wheezing or SOB	12	35[c]	32
Attack of SOB or cough after exercise	15	21[c]	16
Bronchitic symptoms	2	21[c]	19
Usual morning cough	3	28[c]	26
Usual morning phlegm	6	34[c]	30

[a]In the last 12 months.
[b]In the last 6 weeks (over crab season).
[c]$P < 0.05$ (comparison to early-season survey by the McNemar's test).

Microscopic Findings

Microscopic analysis of air samples confirmed the presence of a variety of particles including fragments of crab meat and shell. Often one could see evidence of evaporated deposits suggesting that some particles were liquid at the time of sampling. Particles were polydispersed in sizes ranging from micro to millimeters. Examination of the surface of safety glasses confirmed that large particles were accelerated toward the face in the butchering, degilling and cooking areas.

DISCUSSION

We present a longitudinal study over the course of one snow-crab processing season that examines respiratory symptoms, spirometry, specific IgE to crab, and workplace exposures using aerosol monitoring of crab allergen. We found an incidence of asthma-like (26%) and bronchitic (19%) symptoms in workers, most of whom did not have changes in spirometry or in specific IgE to crab. Measurement of crab allergen in aerosol during the early-season survey using a RAST-inhibition assay did not show a clear exposure gradient among jobs and this may have been due partly to wide dispersal of the allergen through the open, unpartitioned plant space. However, allergenic extracts did provide some informative data, such as detection of environmental kanimiso as the product source of allergen. Allergen extracts also showed differences between naive and experienced workers to support a healthy worker effect.

An increased incidence of asthma-like and bronchitic symptoms among crab processors over a single processing season is documented. We report the prevalence of these symptoms at the end of the season and the incidence of new symptoms over the season. Our late season prevalences of symptom complexes are consistent with other reports noted in the literature [Cartier et al., 1984, 1986]. Cartier et al. [1986] reported 19% (57/303) of crab processing workers complained of productive cough and dyspnea and 21% (64/303) had symptoms suggestive of OA. In our study, the 21% late-season prevalence of productive cough (bronchitic symptoms) was similar to that reported by Cartier. However, the late-season prevalence of asthma-like symptoms was 32%; higher than that reported by Cartier. Differences in the case definition or exposures might be a factor(s) influencing prevalence differences.

A study of pulmonary function and productive cough and dyspnea in king crab processing workers from a factory in the state of Washington also yielded results similar to our study. These 15 crab processors were found to have increased prevalence of respiratory symptoms, compared to fish processors not exposed to crab. In addition, skin prick testing with crab meat, dust from the machines and crab shell resulted in immediate skin reactions in some of these

TABLE III. Relative Risk (RR) Among Crab Processing Workers in Alaska, 1998

Risk Factors (n)		RR (95% CI [c]) for asthma-like symptoms (n = 92)	RR (95% CI [c]) for bronchitic symptoms (n = 105)
Age	≥ 35 years old	1.0	1.0
	< 35 years old	1.7 (0.8–3.4)	4.4 (1.6–12.3)[d]
Gender	Female	1.0	1.0
	Male	5.6 (0.8–38.7)	5.0 (0.7–35.8)
Race	Non-white	1.0	1.0
	White	0.9 (0.4–1.7)	1.4 (0.6–3.0)
Smoking[a]	No	1.0	1.0
	Yes	1.6 (0.8–3.2)	1.9 (0.9–4.2)
Atopy	No	1.0	1.0
	Yes	0.9 (0.4–1.8)	1.8 (0.8–4.0)
Family history	No	1.0	1.0
of allergies	Yes	2.2 (1.1–4.3)	2.0 (0.9–4.5)
Crab-kanimiso	Negative	1.0	1.0
RAST- IgE[a]	Positive	2.0 (0.7–5.8)	5.2 (2.7–9.8)[d]
Crab-meat	Negative	1.0	1.0
RAST- IgE[a]	Positive	0.6 (0.1–3.7)	2.3 (0.7–7.3)
C. pagurus crab	Negative	1.0	1.0
CAP- IgE[a]	Positive	2.1 (0.9–4.7)	2.8 (1.2–6.5)[d]
Elevated serum	Negative	1.0	1.0
ECP[a]	Positive	3.6 (2.1–6.0)[d]	3.5 (1.5–8.1)[d]
Tenure in	Experienced	1.0	1.0
crab industry	Naive	1.5 (0.8–3.1)	2.2 (0.9–5.3)
High exposure	No	1.0	1.0
categories[b]	Yes	1.3 (0.7–2.5)	1.9 (0.8–4.6)
Job categories	Unloading	1.0	1.0
	Butchering	5.0 (0.7–36.7)	3.7 (0.5–29.1)
	Degilling	4.5 (0.6–32.6)	5.1 (0.7–36.3)
	Packing	3.6 (0.5–25.4)	1.7 (0.2–13.6)
	Case-up	4.2 (0.6–30.8)	3.6 (0.5–27.4)
	Mixed/high	3.6 (0.4–29.5)	3.3 (0.4–27.2)
	Mixed/low	2.0 (0.2–19.2)	3.0 (0.4–25.2)

[a]Status at the end of the season.
[b]Yes (butchering, degilling, cooking), no (packing, case-up).
[c]Denotes confidence interval.
[d]Denotes statistical significant difference.

workers and none in the controls; however, skin test positivity did not correlate with symptoms [Orford et al., 1985]. As was the case in the current investigation, no major changes in spirometry were observed in the participants tested. Another study among crab processing workers that used a criterion of between 15 and 20% change in FEV_1 after bronchodilator administration, yielded a change of 1.4% (4/290) in the subjects [Cartier et al., 1986]. In our investigation, 8 out of 109 workers had new bronchodilator responsiveness at the end of the season using a change of 8% in FEV_1. This criterion has been used as an indication of airways instability in epidemiologic studies [Lorber et al., 1978].

A study among workers with asthma reported an association between cutaneous prick reactivity to crab cooking water and three commercial crab extracts. An association was also found with crab-specific IgE levels and those with asthma. Twelve of 46 subjects with occupational asthma confirmed by immunologic and inhalation challenge tests, also manifested signs and symptoms of allergy after eating crab [Cartier et al., 1986]. In our study, the levels of total and specific IgE to crab were higher in naive workers

TABLE IV. Specific and Total IgE Antibodies, Stratified by Tenure Status Among 96 Crab Processing Workers in Alaska, 1998

	Percent crab-kanimiso IgE		Percent crab-meat IgE		Percent crab-*C. pagurus* IgE		Medians for total IgE kU/L (25th, 75th percentiles)	
Tenure status	January[a]	March[b]	January[a]	March[b]	January[a]	March[b]	January[a]	March[b]
Naive workers (N = 45)	12	10	12	12	12	10	91 (37, 419)	94 (38, 392)
Experienced workers (N = 51)	5	2	2	0	14	11	64 (18, 224)	61 (20, 223)

[a,b]Serum was collected at the beginning (January) and at the end (March) of the crab processing season.

than in experienced workers at the start of the season. This suggests that past exposure to crab processing work may result in the development of IgE antibodies and respiratory symptoms, and that these workers may be less likely to return to this kind of work. This is consistent with a 'healthy worker effect' with the healthier experienced workers less likely to have IgE than those who do not return or than a group of naive workers. We speculate by the time we examined them, that the naive workers had already experienced brief exposures to crab, resulting in IgE production in only some of them, but that selection out of processing work of less healthy workers had not yet occurred among these naive participants. A healthy worker effect in experienced workers is also supported by the observation that naive workers were more likely to develop symptoms.

Although the above finding and the literature point to an IgE mediated mechanism for the development of respiratory health outcomes and selection out of the workplace, we found crab specific IgE in only a minority of incident asthma-like (9%) and bronchitic cases (21%). This lack of IgE formation, as measured by RAST testing developed in our laboratory, was confirmed by commercial CAP testing for crab *C. pagurus* on the same specimens, with the assumption of the presence of cross-reactivity. It is possible that the short interval between the time of baseline and late-season testing limited our ability to detect IgE changes in these workers. It is also plausible that only some of the symptom complexes we detected are related to an IgE mediated mechanism and others are related to irritant mechanisms as we discuss below.

Other mechanisms for the development of symptoms include acute or chronic irritation by agents such as hypertonic solutions originating from seawater, steam from the cooking process, cold air, and cigarette smoking. Despite exposure to cold outdoor air, unloading workers appeared to have fewer symptoms relative to workers inside the facility. This suggests that exposures in the inside of the plant were important contributors to the development of reported symptoms.

We examined atopy by measurement of IgE antibodies to common aeroallergens because it is a risk factor for the development of some types of OA, especially those due to high molecular weight compounds [Malo and Cartier 1993]. In some cross-sectional epidemiologic studies, atopy has been found to predispose to sensitization, whereas others suggest it is unimportant. In longitudinal studies, atopy has not been associated with rate of pulmonary function decline, nor with the development of airway reactivity [Vedal and Chan-Yeung 1989]. In this study, as in a previous report among crab workers, atopy was not noted to be significantly associated with symptom status [Cartier et al., 1986]. However, we found family history of allergy associated with the onset of respiratory symptoms. Interestingly, all eight workers who developed airway hyperreactivity assessed by bronchodilator response had family history of allergies. Perhaps this history is a marker for genetic predisposition for the development of symptoms in crab workers rather than for the development of IgE antibodies.

Inflammation is a major component in asthma; ECP has been used as a marker for eosinophilic inflammation. In this investigation serum ECP was elevated among workers who developed asthma-like and bronchitic symptoms. Previous studies have shown a good correlation between subjects with asthma symptoms and increased levels of ECP [De Blay et al., 1998; Grutters et al., 1999].

We also examined an association of exposure to aerosolized crab allergen to sensitization and the development of symptoms. Studies have shown that the degree of allergen exposure determines the likelihood of immunological sensitization and asthma [Baur et al., 1998]. A recent report showed the highest allergen concentration in air samples analyzed by RAST-inhibition for snow crab proteins, using cooking water extract, from the crab-cracking section and the exit point of the cooling basin [Weytjens et al., 1999]. In our study, we conducted allergen quantification using both crab meat and kanimiso extracts. Although we did not have sufficient numbers of detectable personal environmental samples to definitively characterize job–exposure or exposure–outcome relationships, the highest individual exposures to kanimiso allergen were found in butchers, degillers, and packers. This suggests a wide physical distribution of the allergen in the plant. Personal exposure to kanimiso allergen requires further evaluation as a marker of exposure to crab-derived material. In this study the airborne allergen concentrations are expressed in relative units rather than weight units because the extracts used for reference standards were complex mixtures of proteins and not pure allergens. While this makes direct comparisons with other studies difficult, one can compare the distribution of allergens within facilities, and it is noteworthy that similar processes were identified as having the highest allergen exposures in this study and two previous reports [Griffin et al., 1994; Weytjens et al., 1999]. The collection methods, extraction protocols and analytical procedures used to determine airborne allergen levels are not standardized. Further work is needed for the study of environmental and occupational allergen exposures in the workplace.

The findings of this report are subject to several limitations. First, a small sample size restricted further data analysis such as multivariate analysis. Second, the duration of follow-up of 6 weeks was perhaps too short for the development of new sensitization. Finally, the small number of detected crab derived allergen levels limited the potential to assess exposure–response relationships based on air sampling for allergen.

Despite these limitations, increased cross-season development of respiratory symptoms in particular jobs such as butchering and degilling were observed, suggesting that aerosols generated in these operations are able to trigger respiratory symptoms even in the absence of allergic sensitization.

To minimize the extent of adverse health effects in this industry, a medical monitoring program should be in place for the early detection and prevention of acute and chronic work-related adverse health effects. Workers who develop work-related respiratory problems should be given the opportunity to transfer to an area of the facility which is less hazardous to them. Engineering controls to reduce aerosol exposure should be installed where feasible, including enclosures for spray-generating tasks such as butchering, degilling, and cooking. In areas where these tasks are conducted, ventilation should be modified to direct airflow away from workers.

In summary, asthma-like and bronchitic symptoms may be associated with both personal risk factors and process-related exposures encountered during crab processing. Both allergic and non-allergic mechanisms appear to be involved. Continued efforts to control exposure to crab-derived materials are prudent and may decrease the incidence of respiratory symptoms in crab processing workers. More sensitive environmental assessment methods and standardization will be required to fully assess the role of airborne allergens in the development of respiratory symptoms in such workplaces.

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