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Eye and Respiratory Symptoms in Poultry Processing Workers Exposed to Chlorine By-Products

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Background *CDC/NIOSH responded to a request to investigate complaints of eye and respiratory irritation among workers in a poultry processing facility's evisceration department.*
Methods *Investigators administered symptom questionnaires and sampled for chlorine and chloramines. Spirometry was performed on workers before and after their work shift.*
Results *Symptoms were significantly more prevalent in evisceration workers than in dark meat workers (a control group). Air concentrations of chloramine compounds (i.e., trichloramine and 'soluble chlorine') were significantly higher in the evisceration area than the dark meat area. Exposure levels were significantly higher for employees reporting various symptoms compared to employees not reporting those symptoms. Mean trichloramine exposure concentrations were significantly higher in workers with significant cross-shift declines in lung function; air concentrations of 'soluble chlorine' were higher as well, however, not significantly so.*
Conclusions *Results of this evaluation suggest a health hazard may exist from exposure to chloramines.* Am. J. Ind. Med. 49:119–126, 2006. *Published 2006 Wiley-Liss, Inc.*†

KEY WORDS: poultry processing; chlorine; chloramines; trichloramines; eye irritation; respiratory irritation

INTRODUCTION

In May 2002, the National Institute for Occupational Safety and Health (NIOSH) received a health hazard evaluation (HHE) request for technical assistance from the Occupational Safety and Health Bureau of the Iowa Division of Labor. The request stated that employees in the evisceration department of a poultry processing facility in the state were experiencing symptoms such as eye and respiratory irritation thought to be related to chlorine exposure; however, environmental sampling for chlorine was negative. They requested assistance in determining the cause of worker's symptoms.

BACKGROUND

Facility Operations

The facility processes approximately 17,000 turkeys on each production shift.

There are three 8-hr shifts per day, two for turkey processing while the third is for cleaning.

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Turkeys are unloaded by hand and hung by their feet on a shackle conveyor, then electrically stunned and killed by a mechanical throat slitter. The turkeys then pass through a "bleed-out" room into a hot-water scald tank. Following the scald tank, the turkeys are mechanically de-feathered in the picking room. After the picking room, an employee in the pinning room inspects the birds for any remaining feathers, and removes them as necessary. Additionally, hock cutters remove the legs and feet from the body of the turkeys, then the bodies are re-hung on the evisceration line.

Activities that employees perform in the evisceration line area include removal of the turkeys' entrails, head, neck, and lungs, as well as trimming off defective parts of the birds. U.S. Department of Agriculture (USDA) inspection of the birds for visible contamination also occurs on the evisceration line. Substantial amounts of super-chlorinated water are used at a number of stations on the evisceration line for disinfection of the birds. The facility attempts to maintain a concentration of 20 parts per million (ppm) of active chlorine in this water through the addition of sodium hypochlorite. These stations include a bird-scrubber located at the start of the line, reprocessing stations where birds with potential fecal contamination are sent, and the high-pressure inside/outside bird wash. An open trough running throughout the evisceration line area catches the used super-chlorinated water along with discarded or dropped turkey parts. At the end of the evisceration line, the turkeys are split into hind (dark meat) and front (white meat) halves, which are then dropped into tanks of the super-chlorinated water, and chilled to temperatures of 32 to 36°F through ammonia refrigeration.

Following a period of up to 3 hr in the chill tanks, the white and dark meat portions of the turkeys are sent to separate white meat and dark meat departments for further processing and packaging for shipment. Little, if any, super-chlorinated water is used in these processing and packaging departments.

Irritative Symptoms in the Poultry Processing Industry

There have been numerous reports of eye and respiratory tract irritation among poultry processing workers and USDA inspectors during processing steps involving the use of super-chlorinated water, and this is considered to be a widespread problem in this industry [NIOSH, 1989; NIOSH, 1994; Sanderson et al., 1995; Segna, 1998]. Reported symptoms generally are intermittent in nature, vary in severity, and may be accompanied by reports of a "chlorine-like" odor. Whether sodium hypochlorite or chlorine is used as the source of super-chlorination does not appear to account for any differences in the reporting of irritation.

Investigations to identify the cause of irritation and determine appropriate remedial action have been conducted by the USDA, NIOSH, and others at several poultry processing plants. Obvious air contaminants that would cause these symptoms, such as chlorine or ammonia, have not been detected in the air. Chloramines, specifically trichloramine (NCl_3), have been suspected as a primary cause of the reported symptoms because of the interaction between the chlorinated water and the nitrogenous material from the turkeys[Sanderson et al., 1995].

The lack of an acceptable air monitoring technique for chloramines has been a primary obstacle for obtaining conclusive verification of chloramines as a cause of irritation. This also makes it difficult to target control measures, since decreases in exposure levels cannot be verified.

In 1998, researchers at the *Institut National de Recherche et de Sécurité* (INRS) in France developed a sampling and analytical method for assessing workers' exposure to chloramines in a facility that processes green salads in water containing hypochlorite [Hery et al., 1998]. Acute eye and upper respiratory irritation were reported among the workers at the facility, and were thought to be caused by exposure to chloramines, formed from the interaction of the hypochlorite in the water with the nitrogen compounds in the sap proteins released when cutting the vegetables [Hery et al., 1998].

In March 2000, NIOSH investigators conducted an HHE at a poultry processing facility in Virginia, where employees had reported eye, nose, and throat irritation [NIOSH, 2000]. In addition to investigating chlorine and ammonia exposures, the evaluation also included a chloramine exposure evaluation using the INRS method. NIOSH investigators partnered with INRS, which had agreed to supply samplers for the chloramine exposure evaluation, as well as services for sample analysis. In addition to finding inadequate ventilation in the facility, as well as poor control of chlorine levels in the water used in the facility, NIOSH investigators concluded that chloramines may, indeed, be the cause of the irritation reported.

Because of continuing reports of such irritation among poultry plant workers, further requests for HHEs in such facilities, and the absence of other known potential irritants at the facility in question, NIOSH investigators identified the need to further develop a laboratory method for the analysis of chloramines since the French method was no longer available.

MATERIALS AND METHODS

Industrial Hygiene

On the initial site visit to the facility in June 2002, area air samples were collected for screening purposes using two direct reading methods. The first method involved the use of a bellows pump and colorimetric detector tubes (Dräger®, Inc., Pittsburgh, PA) for chlorine and ammonia. Samples were taken at various stations throughout the evisceration line and the dark meat area. Efforts were made to sample near stations where the use of the super-chlorinated wash occurred and in areas where symptoms were reported more frequently. The second screening method involved the use of a Dräger Chip Measurement System (CMS®). This method uses a hand-held analyzer for measurement and evaluation, and a gas- or vapor-specific chip, which is inserted into the analyzer. Side-by-side measurements for chlorine were taken using the CMS® and the detector tubes.

On the second site visit in June 2003, area air samples were collected for chlorine at various stations throughout the evisceration line and the dark meat area (for comparison purposes) using methods similar to those used during the initial site visit. Additionally, full-shift personal breathing zone (PBZ) and area air samples were collected for trichloramines and 'soluble chlorine' (the combination of chlorine compounds such as monochloramine, dichloramine, hypochlorite, and hypochlorous acid) in the evisceration line area and the dark meat area. The NIOSH approach for this sampling incorporated samplers developed using the INRS method. These samplers are a combination of an absorption tube (analyzed for 'soluble chlorine') and a treated filter (analyzed for trichloramine). Samplers were constructed from a tube containing silica gel coated with sulphamic acid and a 37-mm polystyrene cassette containing two quartz fiber filter pads in series soaked in sodium carbonate and diarsenic trioxide. NIOSH laboratory researchers modified the INRS method by using inductively coupled plasma atomic emission spectroscopy (ICP-AES) to analyze both the sample tube and the filters rather than an ion selective electrode technique for the tube and ion chromatography for the filter. Analysis involved a simple extraction with sulfamic acid followed by ICP-AES analysis of chlorine for both tube and filter.

During sampling, air was pulled through the silica gel-containing tube prior to passing through the filter-containing cassette. The 'soluble chlorine' compounds were collected on the silica gel-containing tubes, while the trichloramine passed through the tube. The trichloramine was then trapped separately by the filters as it chemically reacted with them. The air samples were collected using calibrated SKC Hi-Flow sampling pumps (SKC, Inc., Eighty Four, PA) at a flow rate of one liter per minute (L/min). The sampling pumps were pre- and post-calibrated using a primary standard to verify the flow rate. Samplers were shipped overnight to the NIOSH laboratory after daily sampling. Upon receipt, the samples were immediately desorbed and stored in the dark in the refrigerator until analysis.

During analysis of the tubes, extraction was performed by placing the impregnated silica gel from the tube into a 20 ml vial. Ten microliter of a 1 gram per liter (g/L) sulfamic acid solution was added to each vial and allowed to sit for 1 hr with occasional agitation. The sample extracts were decanted into another vial and refrigerated until analysis. Samples were analyzed for chloride using an ICP-AES method at a wavelength of 134.724 nm. An instrumental limit of detection (LOD) was determined to be 0.7 micrograms (μg)/sample.

During analysis of the filters, each filter was removed from the cassette, placed in a 20 ml sample vial, and 10 ml of deionized water was added. The filters were sonicated for 1 hr and allowed to sit an additional 30 min for the solution to cool. Sample filters were refrigerated and then filtered through a 0.45 μm teflon filter prior to analysis on the ICP-AES at a wavelength of 134.724 nm. An LOD for trichloramine was determined to be 0.6 μg/sample.

Medical

During the initial site visit in June 2002, workers on the day shift of the evisceration and dark meat departments were administered a questionnaire. The evisceration workers were chosen because of the extensive use of super-chlorinated water in their department and because the concerns originated there. The dark meat workers were chosen as a comparison group because of the limited use of super-chlorinated water in that department.

The questionnaire was administered by NIOSH personnel in either Spanish or English. It consisted of questions concerning demographics (age, gender, job title, years worked, work department), personal history of allergies, eczema, asthma, and smoking, upper and lower respiratory symptoms at work in the last 4 weeks, and whether those symptoms remained the same, got worse, or got better on days off work. Upper respiratory and eye irritation symptoms included burning or stinging eyes, watery eyes, itchy or runny nose, stuffy nose, frequent sneezing, and sore throat. Lower respiratory symptoms included wheezing, shortness of breath, and chest tightness. Cough was also included on the questionnaire and can be either an upper or lower respiratory symptom. A subject was considered to have ''asthma symptoms'' if they reported wheezing, or any two of the following three symptoms: cough, shortness of breath, and chest tightness. This does not imply that they had been diagnosed with asthma by a physician. Symptoms were considered work-related if they were present at work, and improved or disappeared on days away from work.

Because a significant proportion of workers reported asthma symptoms on our initial visit, and because asthma has been reported in swimming pool personnel exposed to chloramines [Thickett et al., 2002], we decided to examine the relationship of both upper and lower respiratory symptoms to chloramine exposure. Workers who met the case definition for work-related asthma symptoms (all of whom also had at least one upper respiratory symptom) on the initial screening questionnaire and a comparison group of workers who reported no work-related respiratory symptoms were asked to participate in the follow-up evaluation in June 2003. Informed consent was obtained.

During the follow-up site visit in June 2003, pre- and post-shift spirometry was performed on each participant. Spirometry refers to the measurements of exhaled air volume and flow rates from individuals who are coached by trained technicians using either volume-based or flow-based measuring equipment. The important measurements include forced vital capacity (FVC) or the greatest volume of air exhaled from a maximal inspiration to a complete exhalation; the forced expiratory volume in 1 s (FEV1) or the volume of air exhaled in the first second of a FVC maneuver; and the ratio between these two values: FEV1/FVC. These measurements were made using a dry rolling-seal spirometer (volume-based system) interfaced to a dedicated computer. All procedures conformed to standard guidelines [American Thoracic Society, 1995]. At least three maximal expiratory maneuvers or FVC maneuvers were performed at each session. The selection and interpretation of results also conformed to standard guidelines [American Thoracic Society, 1991]. Predicted values were determined from published reference equations [Hankinson et al., 1999]. A brief follow-up questionnaire was administered at the end of the shift to determine if upper or lower respiratory symptoms noted above were present during the shift that the PBZ sampling was performed for each participant.

Statistical Analysis

Crude associations between work area and symptoms were evaluated using 2×2 contingency tables and the Chi square test. To adjust these analyses for smoking status (current, former, or never), logistic regression models were constructed. Odds ratios (OR) were reported as a measure of association. We also calculated 95% confidence intervals (CI). If the 95% CI excluded one, then the OR was considered statistically significant.

The air sampling exposure measures (trichloramine, and 'soluble chlorine' concentrations) were not normally distributed, and were log-transformed for data analysis. Values for sampling results that were below the minimum detectable concentration were estimated by dividing the MDC by two [Hornung and Reed, 1990]. Concentrations of trichloramine, and soluble chlorine for the two work areas were compared using the *t*-test. In addition, *t* tests were used to determine whether PBZ exposures levels differed for those with and without respiratory symptoms, as well as those with and without meaningful declines in FEV1 (>10%). Geometric means were used to report exposure concentrations. P values of <0.05 were considered statistically significant.

The *t*-test was used to evaluate whether subjects with and without asthma symptoms had differing mean changes in cross-shift FEV1. Multivariable linear regression models were used to examine this relationship while adjusting for smoking status.

SAS software Version 8 (SAS Institute, Cary, NC) was used for statistical analysis.

RESULTS

On the initial site visit, chlorine was not detected at any sampling station by either sampling method used. Sampling locations included those which use or are near large quantities of the super-chlorinated wash such as the 1st Bird Brush Wash, the Inside/Outside Wash, and the Chillers. Similar results were obtained for samples taken in the dark meat area. Again, chlorine was not detected at any sampling station by either sampling method used.

Direct-reading Dräger tubes were used in various locations of the facility to measure ammonia levels in the air. Five samples were drawn in and around areas such as the engine room (from where the chemical is pumped), the trimmer area outside the door of the engine room, and the chillers. Ammonia was not detected in any sample.

The concentration of chlorine in the wash water was reported to be 20 ppm as recorded in company records for that day. This concentration is equal to the level required by the USDA for spray water on evisceration lines and in salvage and reprocessing areas of poultry processing facilities.

During the initial site visit, questionnaires were administered to 109 of 115 (95%) eligible employees (68 of 69 [98%] in evisceration and 41 of 46 [89%] in dark meat). The participation rate for evisceration was slightly higher than dark meat because four workers in dark meat only spoke Lao and a translator was not available. Workers in both departments were similar in age, tenure, and history of atopy. Evisceration workers were significantly more likely to be current or former smokers, however. These results are summarized in Table I.

The odds of work-related wheezing, coughing, sneezing, and watery eyes were significantly higher among evisceration workers (see Table II). Work-related sore throat, burning or stinging eyes, and asthma symptoms were also more frequently reported by evisceration workers, but this was not statistically significant. The odds of shortness of breath, chest tightness, itchy runny nose, and stuffy nose were not significantly different between departments. Logistic regression models were constructed to control for the potential effects of smoking status (never, former, current smoker), but did not meaningfully alter the relationships seen above, with the exception of burning or stinging eyes, the odds of which became statistically significantly higher in evisceration workers after controlling for smoking. These results are also in Table II.

Forty-seven persons were selected to participate in the second survey in June 2003, 23 of whom met our screening questionnaire definition of work-related asthma symptoms and 24 of whom reported no work-related respiratory symptoms. At the time of the second survey, seven of these

TABLE I. Demographics and Selected Characteristics by Department, Initial Site Visit: June 27, 2002; Poultry Processing Facility

	Evisceration	Dark meat
Participation rate	68/69 (98%)	41/46 (89%)
Mean age (years)	36	39
Mean tenure at the facility (years)	8	7
Gender		
Male	57%	44%
Female	43%	56%
History of atopy[a]	21%	23%
Smoking status		
Current*	24%	5%
Former*	32%	13%
Never*	44%	82%

[a]Atopy is history of any of the following: hay fever or other allergies (except for allergies to medications), asthma, or eczema.
*$P < 0.05$.

persons were no longer employed, three were not present at the time of the survey, two had changed shifts, and one chose not to participate. The remaining 34 employees participated fully in the environmental sampling and the medical evaluation, including the pre- and post-shift spirometry and the questionnaire. Sixteen worked in dark meat and 18 in evisceration. No chlorine was detected at any location tested using Dräger tubes.

Sampling for trichloramines and 'soluble chlorine' revealed considerably higher levels in the evisceration line area versus the dark meat area. Table III compares the full-shift PBZ air sampling results. The geometric mean TWA concentration of trichloramine was significantly higher in the evisceration department than in the dark meat department (5.07 vs. 1.20 micrograms per cubic meter (μg/m^3), $P < 0.01$), as was the geometric mean TWA concentration of soluble chlorine (63.45 vs. 9.38 μg/m^3, $P < 0.01$).

Workers who reported either wheezing, or two of the following three symptoms: chest tightness, shortness of breath, or cough on the day they were surveyed were considered to have current symptoms of asthma. Forty-four percent of workers with current asthma symptoms were current or former smokers, compared to 20% of those without current asthma symptoms ($P = 0.20$). In addition, workers who reported current asthma symptoms had higher geometric mean exposure to 'soluble chlorine' than those without current asthma symptoms (47.76 μg/m^3 vs. 18.75 μg/m^3, $P = 0.04$) (Table IV). Geometric mean concentrations of trichloramine did not differ significantly between those with and without current asthma symptoms (2.85 μg/m^3 vs. 2.48 μg/m^3, respectively).

Three persons had significant cross-shift declines (>10%) in their FEV1 [Townsend, 2000]. Two of these persons were not able to meet reproducibility criteria on their pre-shift spirometry; one had normal results and one (a smoker) showed borderline restriction. Both, however, were able to meet criteria on their post-shift spirometry. Including these two individuals, the geometric mean TWA trichloramine exposure concentration in persons with a significant cross-shift decline in their FEV1 was 21.74 μg/m^3 compared to 2.09 μg/m^3 in those without a significant cross-shift declines in their FEV1 ($P = 0.01$). Geometric mean TWA 'soluble chlorine' compounds exposure concentration was 70.5 μg/m^3 in those with a significant cross-shift decline in FEV1 compared to 21.86 μg/m^3 in those without ($P = 0.10$).

Geometric mean TWA 'soluble chlorine' concentrations were significantly higher in persons who reported burning or stinging eyes, itchy or stuffy nose, cough, asthma symptoms,

TABLE II. Work-Related Symptoms by Department, Initial Site Visit: June 27, 2002; Poultry Processing Facility*

	Evisceration (n = 68)	Dark meat (n = 41)	OR (95% CI)	Adjusted OR[b] (95% CI)
Itchy, runny nose	32 (47%)	18 (44%)	1.09 (0.50, 2.38)	1.41 (0.60, 3.42)
Watery eyes	31 (46%)	5 (12%)	5.86 (2.05, 16.79)	7.00 (2.43, 23.89)
Frequent sneezing	30 (44%)	8 (20%)	3.16 (1.27, 7.85)	4.89 (1.84, 14.29)
Cough	28 (41%)	5 (12%)	4.90 (1.71, 14.06)	6.16 (2.14, 20.96)
Burning or stinging eyes	27 (40%)	9 (22%)	2.27 (0.93, 5.51)	3.29 (1.26, 9.22)
Asthma symptoms[a]	18 (26%)	5 (12%)	2.52 (0.86, 7.43)	2.77 (0.93, 9.54)
Stuffy nose	17 (25%)	10 (24%)	1.00 (0.41, 2.46)	1.79 (0.68, 4.95)
Wheezing	15 (22%)	2 (5%)	5.38 (1.16, 24.91)	5.91 (1.44, 40.38)
Sore throat	14 (21%)	4 (10%)	2.33 (0.71, 7.66)	3.15 (0.96, 12.49)
Shortness of breath	10 (15%)	9 (22%)	0.59 (0.22, 1.62)	0.69 (0.23, 2.05)
Chest tightness	10 (15%)	6 (15%)	0.98 (0.33, 2.93)	1.16 (0.35, 3.98)

*Defined as experienced at work during the last 4 weeks, but improved on days away from work.
[a]Defined as wheezing, or any two of the following three symptoms: cough, chest tightness, and shortness of breath.
[b]Adjusted for smoking status.

TABLE III. Full-Shift Personal Breathing Zone Concentrations for Chlorine Compounds by Department, Return Site Visit: June 2–6, 2003

	Evisceration ($n = 18$)		Dark meat ($n = 16$)	
	Geometric mean	Range	Geometric mean	Range
Trichloramine*	5.07 $\mu g/m^3$	ND–156.73 $\mu g/m^3$	1.20 $\mu g/m^3$	ND–47.12 $\mu g/m^3$
Soluble chlorine*	63.45 $\mu g/m^3$	10.42–126.32 $\mu g/m^3$	9.38 $\mu g/m^3$	3.52–45.17 $\mu g/m^3$

*Mean concentrations differ by location ($P < 0.01$).

and frequent sneezing, as compared to those who did not report such symptoms, as shown in Table IV. Geometric mean TWA 'soluble chlorine' concentrations were also higher in persons who reported watery eyes and sore throat, but not significantly so. Geometric mean TWA trichloramine concentrations were significantly higher in persons who reported burning or stinging eyes, but not other symptoms. The relationship between asthma symptoms and exposure was also examined while controlling for smoking status. Findings did not change meaningfully for exposure to trichloramine; however, for soluble chlorine, the relationship was no longer significant ($P = 0.13$).

DISCUSSION

Respiratory, especially upper respiratory, symptoms are common among poultry workers, who usually relate their symptoms to chlorine exposure because of symptom correlation with odor. However, numerous evaluations of chlorine levels, including ours, have failed to document chlorine concentrations that could account for these symptoms. It has been postulated that trichloramine produced by the reaction of nitrogenous materials from the poultry and the chlorinated water used to disinfect the birds, may be responsible for these symptoms. This is likely to be an

TABLE IV. Trichloramine and Soluble Chlorine Levels by Respiratory Symptoms, Return Site Visit: June 2–6, 2003

	Trichloramine ($\mu g/m^3$)			'Soluble chlorine' ($\mu g/m^3$)		
	n	Geometric mean	*P*-value	n	Geometric mean	*P*-value
Burning, stinging eyes						
Present	12	5.77	0.02	10	56.85	<0.01
Absent	22	1.66		22	16.60	
Itchy or stuffy nose						
Present	11	4.61	0.13	9	66.23	<0.01
Absent	23	1.95		23	16.50	
Cough						
Present	9	4.08	0.31	8	58.16	<0.01
Absent	25	2.18		24	18.26	
Frequent sneezing						
Present	6	5.36	0.21	5	95.48	<0.01
Absent	28	2.20		27	18.95	
Watery eyes						
Present	6	2.69	0.94	6	36.44	0.35
Absent	28	2.55		26	22.23	
Sore throat						
Present	3	3.39	0.75	2	70.22	0.19
Absent	31	2.50		30	22.73	
Asthma symptoms*						
Present	9	2.85	0.82	9	47.76	0.04
Absent	25	2.48		23	18.75	

*Workers who reported either wheezing, or two of the following three symptoms: chest tightness, shortness of breath, or cough on the day they were surveyed were considered to have current symptoms of asthma.

issue in a variety of other workplaces, as well. Beef and pork processing plants also use chlorine and chlorine compounds to disinfect meat. Similar symptoms have also been reported in vegetable processing and in indoor swimming pools, where exposures can affect not only workers but patrons.

In our study, trichloramine did not appear to be the predominant chlorine compound produced. This corresponds, however, to the results reported by INRS in their study of chloramine exposure in a green salad processing plant [Hery et al., 1998]. Their reported results showed that, unlike swimming pools where chloramine exposure is mainly composed of trichloramine, between 30% and 70% of the amount of chlorine species in the atmosphere of the facility were chlorine species trapped on the silica gel tube (i.e., the soluble chlorine) rather than trichloramine. It was suggested that the majority of the soluble chlorine trapped on the tube could be composed of mono- and dichloramine. One reason given for this was the fact that aerosolization of the chlorinated water was much more intense in the facility, as compared to a swimming pool environment, which would lead to a proportionally higher emission of mono- and dichloramine [Hery et al., 1998]. This reasoning may help explain the higher quantities of 'soluble chlorine' measured at this poultry processing facility, where aerosolization can easily occur due to the number of spray washes used throughout the evisceration area.

Despite the small number of participants in this study, statistically significant positive associations were demonstrated between soluble chlorine concentrations and burning or stinging eyes, itchy or stuffy nose, cough, and frequent sneezing. In addition, trichloramine concentrations were positively associated with burning or stinging eyes.

A larger sample size might have given us the power to detect differences in other symptoms as well, and we are looking for additional sites to conduct this protocol, both to confirm findings and to increase sample size.

It is expected that trichloramine and soluble chlorine compounds would cause similar health effects. In this evaluation, soluble chlorine compounds predominated, and therefore more symptoms were associated with exposure to them. Soluble chlorine has been related to irritative symptoms in green salad processors, where it is generated in larger quantities than trichloramine [Hery et al., 1998]. In swimming pools, trichloramine predominates and has been related to irritative symptoms in lifeguards and swimming pool instructors [Hery et al., 1995]. In addition, trichloramine has been reported to cause asthma [Thickett et al., 2002].

Reported symptoms of asthma on the day of the survey corresponded to higher concentrations of soluble chlorine. In addition, persons with cross-shift declines in FEV1 of $>10\%$ had significantly higher PBZ concentrations of trichloramine and non-significantly higher PBZ concentrations of soluble chlorine. This represents only three people, two of whom were not able to meet reproducibility criteria on their pre-shift spirometry. However, one of the authors (E.P.) personally observed these individuals perform their spirometry, and was confident that the problem was a lack of familiarity with the testing, as opposed to poor effort. In addition, they were able to meet reproducibility criteria on post-shift spirometry, which is where an intentional lack of effort would be more likely. Therefore, we felt it was worth presenting the data even with these limitations.

Other limitations of this study include the intermittent and unpredictable nature of the symptoms, which restricted our ability to perform spirometry and environmental sampling on days when symptoms occurred. Reasons for the intermittence may include fluctuations in chlorine concentration in the water and in the amount of nitrogenous material from the turkeys. An additional limitation was the comparatively high minimum quantifiable concentration (MQC) values for the soluble chlorine in comparison to the minimum detectable concentration (MDC) value for soluble chlorine and the MQC and MDC for trichloramine. Although the instrumental LOQ was much lower, the method LOQ (upon which the MQC is based) was estimated from the first recovery study performed by the NIOSH laboratory during method development. The estimate was based on a desorption efficiency less than the NIOSH acceptable limit of 75% for media spikes of 55 μg/sample. While some data points do fall between the MQC and the MDC, the statistical analysis lends significant support to the observed trend of higher levels in the evisceration line compared to the dark meat area, suggesting this did not have an important impact on our findings.

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