Dose-Response Relationships Between Occupational Aerosol Exposures and Cross-Shift Declines of Lung Function in Poultry Workers:: Recommendations for Exposure Limits

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Abstract **Author Information** **Article Outline**

Numerous articles have been published regarding the adverse respiratory health consequences of working in intensive livestock and poultry housing. Threshold limit exposure guidelines are not currently applied to this environment, but they are essential to implement and monitor effective environmental controls. Previous dose-response research work with swine workers has resulted in exposure limit recommendations of 2.5 mg/m^3 total dust, 0.23 mg/m^3 respirable dust, 100 EU/m^3 endotoxin, and 7 ppm ammonia. No similar recommendations have been reported previously for poultry workers. Therefore, an industry-wide study was conducted to examine dose-response relationships of bioaerosol exposures and worker respiratory health. A total of 257 poultry workers were studied for respiratory symptoms, pulmonary function, and exposure to dust (total and respirable), endotoxin (respirable and total), and ammonia. Details of the sampling plan and environmental assessment are described elsewhere. Relationships between exposures and response were studied by correlation and multiple regressions. Significant dose-response relationships were observed between exposures and pulmonary function decrements over a work shift. Exposure concentrations associated with significant pulmonary function decrements were as follows: 2.4 mg/m^3 total dust, 0.16 mg/m^3 respirable dust, 614 EU/m^3 endotoxin, and 12 ppm ammonia.

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Approximately 700,000 persons work in animal confinement facilities in the United States, [1] with an estimated 80,000 full-time equivalent poultry farm workers. [2] In the late 1950s, poultry production evolved into a mass production industry. Research has confirmed the negative impacts of poultry-house exposures on the respiratory health of workers. Poultry workers have a high prevalence of acute and chronic work-related symptoms, including cough, phlegm, eye irritation, dyspnea, chest tightness, fatigue, nasal congestion, wheezing, sneezing, nasal discharge, headache, throat irritation, and fever. [3–11]

The changes in patterns of lung function in poultry workers are suggestive of primary obstructive disorders with less consistent indication of restrictive functional changes. Baseline measures of forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) were found to be significantly lower than normal predicted values in chicken breeders. [12] Cross-shift decreases in FEV_1 were more pronounced at chicken-handling work sites where dust and endotoxin levels were high. [5] A study of live-hang shacklers revealed small but significant cross-shift decreases in FVC and FEV_1. [8,13] Significant cross-shift declines in FEV_1 and forced expiratory flow between 25 and 75 percent of lung volume ($FEF_{25–75}$) were detected in a study of turkey, broiler, and layer workers. [14] Chicken catchers were found to have significant decreases in FEV_1 and FVC over the work shift. [9] Likewise, significant cross-shift declines in FEV_1 and FVC were observed in turkey workers exposed to high concentrations of dust, endotoxin, ammonia, and bacteria. [10] Poultry growers and catchers exhibited significantly lower baseline measures of FEV_1, FVC, and FEF_{25} than normal predicted values. [11]

Environmental studies in live poultry facilities have quantified ammonia, dust, bacteria, and endotoxin in ranges in which health effects have occurred in other occupational settings. [9,10,15–20] Dust can act as a non-specific irritant by overwhelming the clearance mechanisms of the respiratory tract. Endotoxins, derived from the lipopolysaccharide portion of gram-negative bacterial cell walls, are inflammatory substances capable of neutrophil recruitment, macrophage activation, complement activation, and histamine release. [21] Ammonia, a by-product of bacterial action on body excreta, is adsorbed to dust particles, inhaled, and distributed through the respiratory tree to exert effects as an alkaline respiratory irritant. [22]

Dose Response of Poultry Exposures

Although no dose-response studies with poultry workers have been available previously, at least one laboratory model demonstrated a dose-gradient response between concentration of poultry dust extract and obstructive respiratory pathology. The contractile activity of non-sensitized guinea pig tracheal rings was found to be dose-dependent on the concentration of water-soluble poultry dust extract, suggesting non-specific inflammatory reaction in airway smooth muscle. [11,23]

In addition, poultry-worker field studies have shown that greater cross-shift declines in FEV_1 were correlated with higher levels of dust and endotoxin. [5] Likewise, turkey growers working in barns with relatively high concentrations of dust, endotoxin, ammonia, and total viable bacteria demonstrated the lowest pre-shift

FEV_1 and FVC. [10] Broiler growers, who are exposed to relatively high concentrations of respirable dust and respirable endotoxin (compared with layer operators, turkey farmers, and loaders/shacklers), showed the greatest cross-shift declines in FEV_1 and FEF_{25-75}. [14]

Evidence for the time component of dose-response relationships has also been suggested in several studies. Frequency of reported respiratory symptoms in egg producers was correlated with hours per week worked in laying facilities. [2] Morris et al [9] found that chicken catchers with 5 or more years of occupational exposure reported more chronic respiratory symptoms and had lower baseline pulmonary function measures compared with workers exposed for fewer than 5 years. Reynolds et al [10] found higher prevalences of respiratory symptoms and significantly lower FEV_1 and FVC in persons who had worked in the turkey industry for longer than 10 years. Similarly, Zuskin et al [11] found that growers and catchers who were occupationally exposed to poultry for more than 10 years had higher prevalences of acute and chronic respiratory symptoms, and significantly lower FVC, than those with fewer years of exposure. [11]

Environmental controls, the basis for prevention of occupationally induced respiratory diseases, are based on recommended standards, which in turn are based on established dose-response relationships. If threshold levels for exposure variables can be determined, then exposure guidelines can be recommended, environmental control programs can be targeted and monitored, and the respiratory health of poultry workers can be protected. The objectives of this study are to: (1) determine if dose-response relationships exist between environmental dust, endotoxin, and/or ammonia concentrations and cross-shift changes in FEV_1 and FEF_{25-75}; and (2) determine the specific concentrations of dust, ammonia, and endotoxin that are related to respiratory dysfunction.

Methods

Overview

This study reports new results from a previously reported in-depth multiphase study of occupational exposures and health risks in the poultry industry. [2,14,24] The research described here is an expansion of the previous study and focuses on dose-response relationships and threshold environmental concentrations.

Study Population

A total of 257 poultry workers (30% women, 70% men) were recruited from the complete Iowa membership rosters of the relevant producer organizations, including 124 turkey growers/loaders and 92 egg producers. There were 101 telephone contacts of turkey producers. Twenty-four were either out of business or had range production, leaving 77 eligible. Fifty-one (60%) agreed to participate. With regard to egg producers, 112 of 266 agreed to participate (42%), from which there were usable data for 92 subjects. Additionally, 26 broiler growers and 15 shacklers were recruited from the *US Poultry Industry Directory* and the *US Who's Who in the Egg and Poultry Industries*. The exposed population was 23% women and 77% men. A non-exposed blue-collar comparison group was studied, consisting of 111 area postal workers and 39 employees at a local small electronics plant. The comparison group was assembled from 100% samples of these workers and included 63 women (42%) and 87 men (58%).

Medical Evaluation

Modified standardized American Thoracic Society questionnaires, [25] with additional questions to assess occupational and exposure histories, were administered by a trained interviewer. Pulmonary function tests were conducted by a trained research assistant who used a Spirotech S500 spirometer (Ohio Instruments). American Thoracic Society guidelines for spirometry were followed. [25] Pulmonary function tests were performed before and after a work period (exposure periods varied from 2 to 4 hours) to assess cross-shift changes.

Environmental Evaluation

Personal sampling was conducted for total and respirable dust, total and respirable endotoxin, and ammonia. Ammonia was quantified by attaching passive diffusion tubes (Sensidyne) to poultry workers during their work shift. Dust samples (National Institute for Occupational Safety and Health [NIOSH] Method 0500) were collected gravimetrically on 5-µm pore, 37-mm low ash polyvinyl chloride membrane filters housed in two-stage closed cassettes in line with personal air sampling pumps (Gelman, Inc), using flow rates of 1 to 2 L per minute. Respirable samples (NIOSH Method 0600) were collected by incorporating mine safety appliance cyclone pre-selectors into sampling trains, with flow rates of 1.5 to 1.8 L per minute. Probed respirators (3M 9920) were used for in-mask sampling of total dust in 34 workers who usually wore respiratory protection. After gravimetric analysis, total and respirable samples were analyzed for endotoxin (by NIOSH methods) using the QCL1000 end point method of the Limulus amebocyte lysate assay. [26]

Statistical Analysis

Relationships of cross-shift lung function changes (FEV_1 and FEF_{25-75}) were examined relative to environmental concentrations of total and respirable dust, total and respirable endotoxin, and ammonia. Initially, univariate procedures were used to yield descriptive statistics for each variable of interest. Histograms were examined to evaluate normality of distributions. Because the data were not normally distributed, they were log transformed for evaluation. Non-parametric Spearman correlation coefficients were calculated to determine relationships among environmental exposures, and between environmental exposures and lung function changes.

The data on concentrations of total and respirable dust, total and respirable endotoxin, and ammonia were divided into quartiles, and the pulmonary function test data from subjects within these exposure quartiles were examined statistically. Bivariate analysis was performed using two-by-two tables, with a correction of 0.5 added to every cell that contained a zero. Cross-shift declines in FEV_1 and FEF_{25-75} at 3%, 5%, and 10% levels were assessed in relation to each quartile of each quantified exposure (total and respirable dust, total and respirable endotoxin, and ammonia). Dependent variables (FEV_1 and FEF_{25-75}) were selected on the basis of previous analyses by Donham et al, [27,28] which found these variables to be significantly associated with environmental exposures in poultry workers. Cross-shift declines of 3%, 5%, 10%, or greater were selected as points for study because these values were used in previous swine confinement studies for recommended thresholds. [27,29] Cross-shift declines in FEV_1 and FEF_{25-75} were calculated as follows:MATH MATH Odds ratios and 95% confidence intervals were calculated for 3%, 5%, and 10% lung function declines (FEV_1 and FEF_{25-75}) for each quartile of exposure.

$$\frac{\text{pre-shift } FEV_1 - \text{post-shift } FEV_1}{\text{pre-shift } FEV_1} \times 100\% = \%\text{ change } FEV_1$$

$$\frac{\text{pre-shift } FEF_{25-75} - \text{post-shift } FEF_{25-75}}{\text{pre-shift } FEF_{25-75}} \times 100\% = \%\text{ change } FEF_{25-75}$$

Multiple logistic regressions were performed by using environmental parameters as main predictor (independent) variables and cross-shift lung function decreases as dependent variables. Each environmental parameter was analyzed individually (controlling for age, years worked in poultry industry, gender, smoking status, and education) in relation to cross-shift changes in FEV_1 and FEF_{25-75} of 3%, 5%, or 10% (or greater). Odds ratios and 95% confidence intervals were determined for each quartile of environmental exposure to facilitate interpretation of dose-response relations.

The significance of trends was evaluated for cross-shift declines in FEV_1 and FEF_{25-75}, as related to increasing quartiles of dust, endotoxin, and ammonia exposures, using Cochran-Armitage trend tests (StatXact-3 software, Cytel). The probability of a trend was determined for each environmental exposure (Ho: $\beta = 0$, indicating no trend) for 3%, 5%, and 10% cross-shift declines in FEV_1 and FEF_{25-75} in separate models. Ninety-five percent confidence intervals and exact *P* values were calculated for β.

Backward elimination models were created to determine which environmental exposures contributed significantly when total and respirable dust, total and respirable endotoxin, and ammonia were considered simultaneously. Separate models were created with 3%, 5%, and 10% cross-shift declines in FEV_1 and FEF_{25-75} as dependent variables, controlling for age, years worked, sex, smoking status, and level of education.

Results

Table 1 shows the major demographic characteristics of poultry workers and controls. The mean number of years worked in the poultry industry was 9.7 (standard deviation, 9.1). Race of poultry workers and controls was primarily white (99.8%).

TABLE 1
Demographic Characteristics of Study Subjects

	Poultry Workers (n = 257)	Controls (n = 150)
% male	77%*	58%
Age	38.8 ± 14.2†	42.1 ± 9.5
Education (y)	12.2 ± 2.1	13.1 ± 2.0
Smoking status (%)		
Never	52.9	42.7
Former	19.1	30.7
Current	28.0	26.7

* Categorical values are expressed as percentages.
† Continuous variables are expressed as mean ± standard deviation.

Table 1

Preliminary data analysis by Donham et al [14] had shown that measures of pre-shift pulmonary function (FEV_1, FVC, FEF_{25-75}, and FEV_1/FVC) did not differ significantly between poultry workers and the comparison group. However, poultry work status was significantly associated with a work shift decline in FEV_1 and FEF_{25-75}, after adjusting for current smoking status. [4] The mean percent cross-shift decline in FEV_1 was 0.02% in controls compared with 1.10% in poultry workers. Mean cross-shift changes in FEF_{25-75} were a 2.10% increase in controls compared with a 1.50% decline in exposed workers (a 3.6% difference). Fig. 1 presents the percentage of workers who had declines in FEV_1 or FEF_{25-75} over shift. Workers more frequently had FEF decrements (ranging from 24% to 45% for 10% and 3% declines, respectively). Decrements in FEV_1 ranged from 4% of workers (10% decline) to 30% of workers (3% decline).

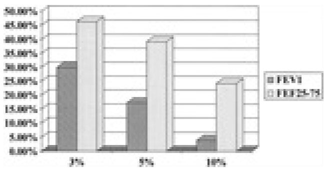

Fig. 1

Environmental Exposures

Table 2 summarizes personal environmental measures of total and respirable dust, total and respirable endotoxin, and ammonia. Ranges for the environmental variables were as follows: total dust (0.02 to 81.33 mg/m ^{3}), respirable dust (0.01 to 7.73 mg/m ^{3}), total endotoxin (0.24 to 39, 167 endotoxin units [EU]/m ^{3}), respirable endotoxin (0.35 to 694 EU/m ^{3}), and ammonia (0 to 75 ppm). Approximately 10% of total dust (based on gravimetric means of airborne samples) was in the respirable range. The respirable portion of endotoxin was 3.7% of total endotoxin. The mean concentration of endotoxin per milligram of dust was 94 EU/mg for the respirable fractions and 245 EU/mg for total endotoxin/total dust.

TABLE 2
Environmental Exposures of Poultry Workers

	n	mean ± SD*
Total dust (mg/m³)	238	8.5 ± 7.8
Respirable dust (mg/m³)	210	0.83 ± 0.98
Total endotoxin (EU/m³)	236	1589.1 ± 5094.1
Respirable endotoxin (EU/m³)	210	58.9 ± 97.3
Ammonia (ppm)	174	18.4 ± 17.5

* SD, standard deviation; EU, endotoxin units.

Table 2

Table 3 summarizes Spearman correlations between environmental variables. Highly significant (eg, $P \leq 0.0001$), moderately strong (eg, $r = 0.4$ to 0.8) Spearman correlation coefficients were observed between all combinations of total and respirable dust, total endotoxin, and respirable endotoxin. Ammonia was weakly ($r < 0.3$) but significantly correlated to total dust and respirable endotoxin. Spearman correlation coefficients between environmental variables and cross-shift changes in lung function (Table 4) revealed that cross-shift decrements in FEV_1 were weakly but significantly correlated to all environmental variables except ammonia. Cross-shift decrements in FEF_{25-75} were weakly and significantly correlated with total dust and total endotoxin only. However, the correlation of cross-shift decline in FEF_{25-75} and respirable dust approached statistical significance for a weak relationship ($r = 0.12$, $P = 0.08$). Cross-shift decrements in FEV_1 and FEF_{25-75} were moderately ($r = 0.66$) and significantly correlated.

Table 3

TABLE 4
Spearman Correlation Coefficients Between Environmental Exposure Variables and Cross-Shift Changes in Lung Function

Variable	% Cross-Shift Decline FEV_1	FEF_{25-75}
Total dust		
r values	0.269	0.275
P values	0.0001	0.0001
Respirable dust		
r values	0.155	0.122
P values	0.0233	0.0788
Total endotoxin		
r values	0.190	0.201
P values	0.0036	0.0025
Respirable endotoxin		
r values	0.157	0.085
P values	0.0232	0.2196
Ammonia		
r values	0.061	0.008
P values	0.5665	0.9443
FEV_1		
r values	1.000	0.658
P values	0.0000	0.0001
FEF_{25-75}		
r values	0.658	1.000
P values	0.0001	0.0000

Table 4

Dose-Response Evaluations

Results of the logistic regressions are summarized in Tables 5 and 6. Trends were generally strong and consistent with increasing odds ratios for lung function declines (FEV and FEF_{25-75}), relative to quartiles of increasing total and respirable dust (Fig. 2), total and respirable endotoxin (Fig. 3), and ammonia exposures. Cochran-Armitage trend tests showed statistically significant trends in odd ratios for 3% and 5% cross-shift declines in FEV_1 and 3%, 5%, and 10% cross-shift declines in FEF_{25-75} (Fig. 1).

Table 5

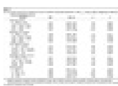

Table 6

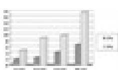

Fig. 2

Fig. 3

Threshold Values

Threshold values were estimated from the lower bound of the lowest quartile range exhibiting statistical significance for a 3% cross-shift decline in FEV_1 (see Table 5). Threshold concentrations predicted by logistic regression results for 3% or greater cross-shift declines in FEV_1 include 2.4 mg/m ^{3} for total dust (Fig. 2); 0.162 mg/m ^{3} for respirable dust; 614 EU/m ^{3} for total endotoxin (Fig. 3); 7.15 EU/m ^{3} for respirable endotoxins (note that this was in the first quartile, 0 to 7.2 EU/m, ^{3} and 0.35 was the lowest actual value); and 12 ppm for ammonia.

Backward Elimination Models

Backward elimination models with 3%, 5%, and 10% (or greater) cross-shift declines in FEV_1 and FEF_{25-75} as dependent variables with continuous environmental independent variables as primary predictors revealed that ammonia was a significant predictor ($P = 0.045$) for a 5% cross-shift decline in FEF_{25-75}. Furthermore, total dust was a significant predictor of a 5% or greater cross-shift decline in FEV_1 ($p = \leq 0.0015$).

Discussion

Previous work showed that poultry workers had significantly larger cross-shift declines in FEV_1 and FEF_{25-75} compared with controls, suggesting that environmental exposures of poultry workers were capable of inducing respiratory dysfunction. [14] Cross-shift declines in FEV_1 and FEF_{25-75} have been noted frequently in animal confinement studies and are indicative of obstructive respiratory disorders. [4,27] The percentages of poultry-exposed workers exhibiting 3%, 5%, or 10% or greater cross-shift declines in FEV_1 were 29.8%, 17.3%, and 3.9%, respectively. Similarly, percentages of poultry workers exhibiting 3%, 5%, or 10% or greater cross-shift declines in FEF_{25-75} were 46.3%, 39.2%, and 24.3%, respectively.

Environmental Exposures

Environmental measures of total and respirable dust, total and respirable endotoxin, and ammonia were highly variable but consistent with other poultry studies. [2,9,10,16–20,30] Ranges of environmental measures were wide because sampling was done in variable seasons and diverse poultry environments (layer houses, broiler houses, turkey houses, load-out operations, and live-hang areas).

Total and Respirable Dusts

Total dust concentrations ranged from 0.02 to 81.33 mg/m. ^{3} Because poultry house dusts are largely organic in content and have many bioactive substances, the Occupational Safety and Health Administration (OSHA) standards (set only for nuisance dusts) for environmental agents are inappropriate in poultry confinement. However, it is interesting to note that the OSHA permissible exposure limit of 15 mg/m ^{3} for nuisance dusts was exceeded in work environments for 7.1% of poultry workers. Sixteen percent of poultry laborers worked in conditions exceeding the American Conference of Governmental Industrial Hygienists (ACGIH) nuisance dust standard of 10 mg/m. ^{3} More importantly, the 4-mg/m ^{3} grain dust ACGIH standard was exceeded for 54.2% of poultry workers, and the recommended swine confinement dust limit of 2.5 mg/m ^{3} was exceeded in 74.8% of personal measures. [27,29,31] It is important to note that concentrations of environmental parameters in this study were based on 2- to 4-hour exposure periods and were not adjusted to 8-hour time-weighted averages.

Respirable dust concentrations ranged from 0.01 to 7.73 mg/m ^{3}. Although only 1.4% of workers were exposed to environmental conditions exceeding the OSHA permissible exposure limit of 5 mg/m ^{3} for Respirable Particles Not Otherwise Regulated, 2.9% exceeded the ACGIH standard of 3 mg/m ^{3}, and 62.4% exceeded the proposed limit of 0.23 mg/m ^{3} of Donham et al [27] for animal confinement exposure limits.

Approximately 10% of total dust (based on gravimetric means of airborne samples) was in the respirable range, which was comparable with 6% reported by Olenchock et al, [16] 5% reported by Jones et al, [18] and 4% to 6% reported by Pickrell [19] in other poultry investigations. These values are in contrast to 30% to 40% of total dust in the respirable range reported as typical of swine confinement buildings. [1,32] However, examination of specific categories of poultry confinement revealed that the respirable portion of total dust in poultry facilities was highly variable, ranging from 5% in layer facilities to 32% in broiler houses. [4] During the period of rapid growth and successive molts in broilers 2 to 6 weeks of age, respirable dust concentrations have been found to increase significantly. [33]

Endotoxin

Total endotoxin exposures ranged from 0.24 to 39, 167 EU/m ^{3} and respirable endotoxin exposures ranged from 0.35 to 694 EU/m ^{3}. Approximately 10% of measures of respirable endotoxin exceeded the proposed limit of 9 ng/m ^{3} (90 EU/m ^{3}), based on cotton dust. [21] The respirable portion of endotoxin was 3.7% of total endotoxin, lower than the 5.7% reported by Olenchock et al [16] and the 11% to 30% reported by Pickrell [19] for poultry confinement. A comparison of the respirable portion of total endotoxin (3.7%) with the respirable portion of total dust (~10%) suggests that endotoxin is not concentrated in smaller, more respirable fractions. This is in contrast to earlier work of Donham et al [32] in the analysis of swine house dust.

Ammonia

Ammonia exposures ranged from 0 to 75 ppm. The OSHA permissible exposure limit of 50 ppm for ammonia was exceeded by only 5.7% of poultry workers. However, 21.3% of workers were exposed to conditions exceeding the ACGIH limit of 25 ppm, and approximately 70% of personal samples exceeded the 7.5-ppm recommendation for swine confinement workers. [27–29]

Spearman Correlations

The fact that moderately strong correlations exist between all combinations of particulate exposures is advantageous for implementing environmental controls, because any control method reducing one of these contaminants will likely reduce all of the above mentioned contaminants. That is, positive correlations imply that effective controls aimed at one exposure will reduce the overall health risks and may result in a lowering of all environmental exposures. However, because ammonia was only weakly correlated with total dust, ammonia control measures independent of dust control are necessary. The independent behavior of primarily vapor phase ammonia compared with particulates is consistent with previous reports. [34]

Dose-Response Evaluation

Assignment of causality between a risk factor and a disease or dysfunction is supported if dose-response relationships can be demonstrated. A dose-response relationship is suggested if the degree of exposure to a suspected risk factor parallels a gradient of risk. [35] Evidence of dose-response trends between poultry confinement exposures (total and respirable dust, total and respirable endotoxin, and ammonia) and impaired lung function (FEV_1 and FEF_{25-75}) was noted from increased odds ratios with increasing environmental exposures. The trends for all exposures were particularly prominent for 5% or greater declines in FEV_1.

Total and Respirable Dust

Statistical significance at the second quartile of total dust exposure for a 3% decline in FEV_1 is consistent with previous findings of Donham et al and Reynolds et al in swine confinement workers. [27,29] Whereas this study suggests a total dust threshold of 2.4 mg/m ^{3}, the swine worker studies resulted in recommendations for maintaining dust levels below 2.5 mg/m ^{3} to promote healthful environmental working conditions. Likewise, statistical significance at the second quartile of respirable dust exposure (0.162 to 0.323 mg/m ^{3}) for a 3% cross-shift decline in FEV_1 is comparable with recommendations for vertically elutriated cotton dust (0.2 mg/m ^{3} in preparation) and swine confine-ment respirable dust (0.23 mg/m ^{3}). [21,27,29,36]

Ammonia

In general, less consistent trends are seen with ammonia exposures. Curiously, decreased odds ratios and larger *P* values were observed for ammonia at the highest quartiles of exposure for both FEV_1 and FEF_{25-75} cross-shift declines. This may be related to distributions of exposures based on work setting. Preliminary results showed that layer operations had the highest ammonia but the lowest total and respirable dust concentrations. The highest quartile of ammonia exposure was in layer operators, who comprised 36% of the exposed group. Because respirable dust concentrations were lower for layer workers, ammonia may have been less adsorbed and thus less distributed through the respiratory tract on inspiration. An alternative explanation is that workers in layer operations, where exposures to ammonia are higher and hours worked are longer, are a self-selective, more tolerant group of workers than those in other segments of the industry where shorter hours are worked. [2] Donham et al [27,28] and Reynolds et al [29] recommended a 7.5-ppm exposure limit for ammonia concentration in swine confinement, which is consistent with a 5% cross-shift FEV_1 decline in this poultry study.

Endotoxin

Odds ratios and 95% confidence intervals reveal significantly consistent trends for lung function declines with increasing quartiles of total and respirable endotoxin. Based on 5% cross-shift declines in FEV_1, significant declines are seen with the first quartiles of total (0.240 to 154.975 EU/m ^{3}) and respirable (0.350 to 7.153 EU/m ^{3}) endotoxin concentration. This threshold range for respirable endotoxin is even lower than suggested by Castellan et al [21] for cotton studies, in which at or below 9 ng/m ^{3} (~90 EU/m ^{3}), cross-shift declines in FEV_1 were not expected. Donham et al [28] defined the endotoxin threshold (as measured in total dust) for swine workers as 0.09 μg/m ^{3} (900 EU/mg), higher than indicated in this study.

Threshold Values

Thresholds suggested by logistic regression results for 3% declines in FEV_1 include 2.4 mg/m ^{3} for total dust, 0.16 mg/m ^{3} for respirable dust, 614 EU/m ^{3} for total endotoxin, 0.35 EU/m ^{3} for respirable endotoxin, and 12 ppm for ammonia. Thresholds were selected for 3% cross-shift declines in FEV_1 on the basis of previous swine confinement threshold studies. [27,29] Environmental variables predictive of 5% FEV_1 declines showed larger odds ratios and more robust statistical significance compared with 3% declines, because relatively small numbers of the comparison group exhibited 5%, as compared with 3%, cross-shift declines.

Previous dose response studies of swine confinement workers have yielded exposure limit recommendations, including total dust at 2.4 to 2.5 mg/m ^{3}, respirable dust at 0.23 mg/m ^{3}, endotoxin at 0.1 μg/m ^{3} (1000 EU/m ^{3}), and ammonia at 7 to 7.5 ppm. [27–29] The threshold limits for ammonia and total dust in this study are very similar to those of swine studies and therefore support previous recommendations of Donham et al and Reynolds et al (2.4 mg/m ^{3} total dust, and 7.5 ppm ammonia) for swine workers. Poultry confinement thresholds for respirable dust and endotoxin (0.162 mg/m ^{3}, 61.4 EU/m ^{3}) seem slightly lower than suggested by Donham et al (0.23 mg/m ^{3}, 100 EU/m ^{3}) for swine workers. When considering the limitations of this dose-response study (eg, loss of information from categorization), there may be no actual differences between the poultry and swine thresholds, suggesting the possibility of a common threshold recommendation for poultry and swine confinement exposures. (It is important to note that swine study recommendations were based on exposure predictions for defined cross-shift changes in FEV_1 using linear regression models. In contrast, threshold values for this study were estimated from the lower bound of the lowest quartile range exhibiting statistical significance for a 3% cross-shift decline in FEV_1.) The current data, combined with previous threshold data of other agricultural dusts (swine [27,29] and cotton, [21] suggest evidence for a generic threshold for workers exposed to agricultural dusts.

Trend Tests

Tests of trend for each environmental exposure variable verified the significance of dose-response relationships between total and respirable dust, total and respirable endotoxin, and ammonia and cross-shift declines in FEV_1 and FEF_{25-75}. Figs. 2 and 3 exemplify the trends of environmental exposure and cross-shift decline in pulmonary function. Figure 2 represents relationships between total dust and FEV_1, and Fig. 3 shows the relationships in endotoxin and FEV_1 response.

Summary

This study supports and extends previous research of dose-response relationships between environmental organic dust exposures in livestock confinement and acute lung function declines. This is the first study of poultry confinement workers to exhibit dose-response trends between increasing environmental dust, ammonia, and endotoxin concentrations with corresponding cross-shift declines in worker lung function. Strong dose-response trends for cross-shift declines in FEV_1 and FEF_{25-75} were observed with both total and respirable endotoxin concentrations. Furthermore, high dust was consistently retained as a significant contributor in all FEV_1 and FEF_{25-75} models when expressed as a categorical variable. Furthermore, specific threshold concentrations were defined (total dust, 2.4 mg/m ^{3}; respirable dust, 0.16 mg/m ^{3}; total endotoxin, 614 EU/m ^{3}; respirable endotoxin, 0.35 EU/m ^{3}; and ammonia, 12 ppm). The thresholds suggested for minimal adverse FEV_1 effect are in general agreement with previous swine confinement studies. The fact that total dust, total endotoxin, and respirable endotoxin were all significantly correlated makes it especially difficult to tease out the “causal” effects of individual components. Organizing the exposures into quartiles seems to fit these data better, possibly because of interactions and non-linearity of the data.

Control Measures

Because the poultry industry is vertically integrated into the control of a few major companies, environmental control efforts are feasible despite dispersion of contract farmers. Short-term solutions to exposure reduction include improved ventilation, use of respiratory protective devices, humidity control, addition of ammonia stabilizers to litter, power washing buildings between production cycles, use of dust binders such as aerosolized vegetable oils, electrostatic precipitation of dust, use of extra oil/fat in feed, and use of the new strains of high oil corn as a feed component.

Conclusions

In summary, relationships observed between ambient environmental exposures and acute changes in lung function for persons occupationally exposed to live poultry include significant dose-response relationships between total and respirable dust, total and respirable endotoxin, and ammonia, and cross-shift declines in FEV_1 and FEF_{25-75}.

Exposure-response thresholds suggested that total dust = 2.4 mg/m ^{3}; ammonia = 12 ppm; respirable dust = 0.16 mg/m ^{3}; total endotoxin = 614 EU/m ^{3}; and respirable endotoxin = 0.35 EU/m ^{3}.

Because the present data are nearly identical to previous recommendations in swine buildings (2.4 mg/m ^{3}, and 0.13 mg/m ^{3} of total and respirable dust, respectively, and 900 EU/m ^{3} for total endotoxin), the basis for development of new legal exposure limits in confined poultry and livestock structures is suggested. [27–29] To protect the estimated 300,000 workers, owners, and operators in this industry, the authors think efforts to develop threshold limit standards should begin in the near future. [3,14]

References

1. Donham K. Respiratory disease hazards to workers in livestock and poultry confinement structures. Semin Respir Med. 1993; 14:49–59.
2. Leistikow B, Petitt W, Donham K, Merchant J, Popendorf W. Respiratory risks in poultry farmers. In: Dosman JA, Cockcroft DW, eds. Principles of Health and Safety in Agriculture. Boca Raton: CRC Press; 1989: 62–65.
3. Donham K, Rubino M, Thedell T, Kammermeyer J. Potential health hazards of workers in swine confinement buildings. J Occup Med. 1977; 19:383–387.
4. Boyer R, Klock L, Schmidt C, et al. Hypersensitivity lung disease in turkey-raising industry. Am Rev Respir Dis. 1974; 109:630–635.
5. Thelin A, Tegler O, Rylander R. Lung reactions during poultry handling related to dust and bacterial endotoxin levels. Eur J Respir Dis. 1984; 65:266–271.
6. Muller S, Bergmann K, Kramer H, Wuthe H. Sensitization, clinical symptoms, and lung function disturbances among poultry farm workers in the German Democratic Republic. Am J Ind Med. 1986; 10:281–282.
7. Brown AM. The respiratory health of Victorian broiler growers. Med J Aust. 1990; 152:521–524.
8. Hagmar L, Schutz A, Hallberg T, Sjoholm A. Health effects of exposure to endotoxins and organic dust in poultry slaughter-house workers. Int Arch Occup Environ Health. 1990; 62:159–164.
9. Morris P, Lenhart S, Service W. Respiratory symptoms and pulmonary function in chicken catchers in poultry confinement units. Am J Ind Med. 1991; 19:195–204.
10. Reynolds S, Parker D, Vesley D, Smith D, Woellner R. Cross-sectional epidemiological study of respiratory disease in turkey farmers. Am J Ind Med. 1993; 24:713–722.
11. Zuskin E, Mustajbegovic J, Schachter E, et al. Respiratory function in poultry workers and pharmacologic characterization of poultry dust extract. Environ Res. 1995; 70:11–19.
12. Stahuljak-Beritic D, Dimov D, Butkovic D, Stilinovic L. Lung function and immunological changes in poultry breeders. Int Arch Occup Environ Health. 1977; 40:131–139.
13. Hagmar L, Schutz A, Sjoholm A. Over-shift decreases in lung function in poultry slaughterhouse workers. Am J Ind Med. 1990; 17:77–78.
14. Donham K, Leistikow B, Merchant J, Leonard S. Assessment of U.S. poultry worker respiratory risks. Am J Ind Med. 1990; 17:73–74.
15. Lenhart S, Olenchock S, Cole E. Viable sampling for airborne bacteria in a poultry processing plant. J Toxicol Environ Health. 1982; 10:613–619.
16. Olenchock S, Lenhart S, Mull J. Occupational exposures to airborne endotoxins during poultry processing. J Toxicol Environ Health. 1982; 9:339–349.
17. Clark S, Rylander R, Larsson L. Airborne bacteria, endotoxin and fungi in dust in poultry and swine confinement buildings. Am Ind Hyg Assoc J. 1983; 44:537–541.
18. Jones W, Morring K, Olenchock S, Williams T, Hickey J. Environmental study of poultry confinement buildings. Am Ind Hyg Assoc J. 1984; 45:760–766.

19. Pickrell J. Hazards in confinement housing—gases and dusts in confined animal houses for swine, poultry, horses, and humans. Vet Hum Toxicol. 1991; 33:32–39.
20. Nielsen B, Breum N. Exposure to air contaminants in chicken catching. Am Ind Hyg Assoc. 1995; 56:804–808.
21. Castellan R, Olenchock S, Kinsley K, Hankinson J. Inhaled endotoxin and decreased spirometric values: an exposure-response relation for cotton-dust. N Eng J Med. 1987; 317:605–610.
22. Donham K. Hazardous agents in agricultural dusts and methods of evaluation. Am J Ind Med. 1986; 10:205–220.
23. Schachter E, Zuskin E, Rienzi N, Godbold J. *In Vitro Pharmacologic Studies of Poultry Dust Extract*. Proceedings of Beltwide Cotton Conference, Memphis, Tennessee; 1994:365–366.
24. Donham K. Health effects from work in swine confinement buildings. Am J Ind Med. 1990; 17:17–25.
25. Ferris B. Recommended standardized procedures for pulmonary function testing in epidemiology standardization projects. Am Rev Respir Dis. 1978; 118:55–88.
26. Reynolds SJ, Milton DK. Comparison of methods for analysis of airborne endotoxin. Appl Occup Environ Hyg. 1993; 8:761–767.
27. Donham K, Reynolds S, Whitten P, Merchant J, Burmeister L, Popendorf W. Respiratory dysfunction in swine production facility workers: dose-response relationships of environmental exposures and pulmonary function. Am J Ind Med. 1995; 27:405–418.
28. Donham K, Haglind P, Petersen Y, Rylander R, Belin L. Environmental and health studies of farm workers in Swedish confinement buildings. Br J Ind Med. 1989; 46:31–37.
29. Reynolds S, Donham K, Whitten P, Merchant J, Burmeister L, Popendorf W. Longitudinal evaluation of dose-response relationships for environmental exposures and pulmonary function in swine production workers. Am J Ind Med. 1996; 29:33–40.
30. Mulhausen J, McJilton C, Redig P, Janni K. Aspergillus and other human respiratory disease agents in turkey confinement houses. Am Ind Hyg Assoc J. 1987; 48:894–899.
31. National Institute for Occupational Safety and Health. Manual of Analytical Methods (NMAM), 4th Ed. Bethesda, MD: US Dept of Health and Human Services, Public Health Service, Centers for Disease Control, NIOSH; 1994.
32. Donham K, Scallon L, Popendorf W. Characterization of dusts collected from swine confinement buildings. Am Ind Hyg Assoc J. 1986; 47:404–410.
33. Yoder MF, Van Wicklen GL. Respirable aerosol generation by broiler chickens. Trans ASAE. 1988; 31:1510–1517.
34. Reynolds S, Parker D, Vesley B, et al. Occupational exposure to organic dusts and gases in the turkey growing industry. Appl Occup Environ Hyg. 1994; 9:493–502.
35. Donham KJ, Thorne P. Agents in organic dust: criteria for a causal relationship. Am J Ind Med. 1994; 25:33–39.
36. Castellan R, Olenchock S, Hankinson J, et al. Acute bronchoconstriction induced by cotton dust: dose-related responses to endotoxin and other dust factors. Ann Intern Med. 1984; 101:157–163.