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Assessing Bovine Exposure and IgE Levels Among Dairy Workers Using a Risk Matrix

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ABSTRACT

Objectives: Dairy workers face a range of occupational risks and outcomes, including acute and chronic respiratory hazards. However, the evidence for negative respiratory outcomes is mixed. Thus, more research is needed to understand the connection between occupational exposures and health outcomes on dairy farms to facilitate the development, implementation, and evaluation of improved programs and processes for injury and illness prevention. This study contributes to this need by evaluating the association between exposure risk and bovine-specific immunoglobulin (Ig)E levels among dairy workers.
Methods: Dairy workers ($n = 36$) self-reported time spent in various dairy-related tasks, as well as personal protective equipment used during all tasks. This information was used to develop job risk matrices for each task and all tasks combined. Serum bovine dander IgE levels were determined for all participants, and the association between exposure and IgE was assessed.
Results: Seven participants (19.4%) had an elevated bovine IgE level. Those with elevated IgE had a mean total risk matrix score of 9.0 compared to 7.6 for those without elevated IgE. In the adjusted models, there were no statistically significant associations between IgE levels and bovine allergen risk matrix scores. However, for the task of herd health, a one-point increase in the bovine allergen risk matrix score was associated with a 1.42 kU/L increase in anti-bovine IgE ($p = .08$).
Conclusion: This work shows the feasibility of using a semi-quantitative task risk matrix to more formally conceptualize dairy worker occupational exposure risk to a respiratory hazard. While not statistically significant, this study identified a positive association between performing herd health tasks and having elevated bovine IgE levels. This suggests task risk matrix approaches may be useful in studying other respiratory hazards in dairy production, including infectious agents.

KEYWORDS
Bovine allergy; dairy workers; task risk matrix

Introduction

In 2022, the United States Bureau of Labor Statistics estimated the incidence rate of non-fatal occupational injury and illness for the dairy cattle and milk production industry was 4.1 cases per 100 full-time workers, higher than the average rate of 3.0 per 100 full-time workers across all industries.[1] This elevated rate reflects the wide range of physical, chemical, biological, and environmental hazards faced by dairy workers. While injuries are a well-documented hazard, adverse health outcomes, including asthma, chronic bronchitis, and other respiratory diseases have also been reported.[2–4] In a Norwegian study of over 1,200 farmers, dairy farmers had 1.6 times greater odds of a chronic bronchitis diagnosis compared to crop farmers.[5] Similarly, in California, dairy workers had 2.73 times greater odds of asthma when compared to workers at a vegetable processing plant.[6] A study of 115 dairy workers in the Western United States found 89% of dairy workers were exposed to endotoxin levels that exceeded recommended exposure guidelines, while 12% of workers were exposed to inhalable dust levels above recommended exposure guidelines.[7] A study of bovine allergen levels in dairy farm in Denmark found an average allergen level of 40,747 $\mu g/m^2$ in dairy stables, compared to 0.09 $\mu g/m^2$ in the bedrooms of non-farmers.[8]

Despite reported high levels of potentially hazardous respiratory exposures, findings on the risk of respiratory outcomes among dairy workers and people living on farms have been mixed, with stronger evidence for a protective effect of allergic disease among children.[3,6,9–12] In the Danish study referenced above, none of the 20 dairy farmers

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tested had a positive skin prick test for bovine allergens, despite the presence of high levels of allergens.[8]

One possible explanation of this paradoxical finding is the hygiene hypothesis, where early life exposure to farms could protect against allergic disease and asthma.[3,13] Other possible explanations for this paradox and the variable outcomes observed across workers include differences in exposure levels due to different job categories or differing personal protective equipment (PPE) use and the "healthy worker effect", where individuals who develop work-related symptoms leave the job early, resulting in lower rates of adverse exposure-related health outcomes among the remaining workers.[14,15]

Thus, more research is needed to understand the connection between occupational exposures and health outcomes among dairy farm workers in order to facilitate the development, implementation, and evaluation of improved programs and processes for injury and illness prevention.

A previous analysis that examined respiratory indicators among both dairy workers and community members as part of the Healthy Dairy Worker (HDW) study in Yakima County, Washington, found similar levels of self-reported respiratory symptoms among dairy workers and community members.[16] However, several dairy workers were found to have elevated levels of anti-bovine IgE, while none of the community members had elevated levels. This suggests possible sensitization to bovine dander. Here, we further analyzed HDW data to characterize the association between occupational exposure to cattle and anti-bovine IgE levels. We hypothesized that workers performing specific dairy farm tasks that are associated with increased exposure to bovine allergens would have higher anti-bovine IgE levels.

Methods

Study population

The structure of the HDW study has been previously described.[16] Briefly, dairy workers were recruited from three large dairies in the Yakima River Valley, a semi-arid region of Eastern Washington State with a large number of dairy farms. Dairy workers ($n = 50$) were recruited at the farms by a staff member who lived in the community. Community members without occupational exposure to cattle were also recruited from surrounding communities to serve as controls. All study participants provided written consent.

This longitudinal study began data collection in 2017 and completed data collection in 2022. Workers completed surveys and blood tests at time of initial recruitment and at four other time points over a 2-year follow-up period. For the analysis presented here, data from dairy worker participants' first (baseline) study visit were used. This visit included a survey that was administered in the participant's preferred language of English or Spanish by trained bilingual study staff. The survey included questions about demographics, occupational tasks, history of working with animals, and medical conditions. For occupational tasks, participants were asked about the total time they worked in the dairy each week, as well as the total time spent in each of five task categories: milking, herd health, feeding, maintenance, and fieldwork. Participants were also asked about PPE used while completing each task. All procedures involving human subjects were reviewed and approved by the University of Washington Human Subjects Review Committee, STUDY00000042.

Serum

Serum samples for IgE quantification were collected within several days of survey completion. Blood was drawn by a trained phlebotomist via venipuncture and was centrifuged within 4 h of collection. After centrifugation, the serum was aliquoted and stored at −80 °C until analysis. Bovine dander specific IgE was measured at the University of Washington Department of Laboratory Medicine by radioallergosorbent assays (Phadia CAP System IgE FEIA for total IgE, ImmunoCAP System Specific IgE FEIA for IgE specific to cow epithelium). Results were reported in thousand units of antibody per liter (kU/L). The limit of detection for this test was 0.1 kU/L. Participants were classified as having elevated IgE if their bovine IgE level was above the limit of detection. Thirty-six participants with complete baseline surveys and available IgE data are included in this analysis.

Bovine allergen risk matrix

A job risk matrix is a semi-quantitative tool used in environmental and occupational health research and practice to characterize the likelihood and severity of an adverse outcome among workers.[17] For this analysis, we constructed a risk matrix for bovine antigens (considered as the outcome) using time spent in tasks (i.e., likelihood of exposure to bovine allergens) and reported PPE use in each task (i.e., severity of exposure to bovine allergens). Minimum necessary PPE to prevent exposure for each task was determined via consultation with industrial hygiene and occupational health experts familiar with farm PPE usage. Based on the PPE use reported by participants when completing each task, a PPE use score for each task was assigned from 0 to 3, where 0 = did not do task, 1 = used all necessary PPE, 2 = used some necessary PPE, and 3 = used no necessary PPE.

Scores for time spent in tasks were assigned based on the distribution of time spent on each task as reported by participants, with the aim of ensuring participants were represented in all score categories. Table 1 indicates the time ranges assigned to scores for each task, where 0 = did not do the task, and 3 = most time spent on the task. For each task, the PPE use score and the time in task score were summed to calculate the task-specific risk score, which could range from 0 if the participant did not do a task to 6, if they spent a significant amount of time on a task and used no recommended PPE. Figure 1 illustrates a task-specific risk matrix for herd health. All five task-specific scores were summed to obtain the overall risk score for each worker. Overall scores could range from 0 to 30, with higher scores indicating a presumed increase in exposure to bovine allergens, and therefore a higher risk of detectable bovine epithelium-specific IgE.

Data analysis

All survey data were collected via the REDCap program hosted by the University of Washington. Data cleaning and analysis were completed in R Software version 4.3.2. All missing data after data cleaning were treated as missing. Anomalous values were reconciled with other survey data when possible. When this was not possible, these data were treated as missing. Values for IgE below the limit of detection were set to the limit of detection. p-values below 0.05 were considered statistically significant.

Descriptive analysis was completed for demographic variables and all variables included in regression models. Distributions of task-specific

Table 1. Time in task (per week) score distribution for risk matrices.

	Score			
Task	0	1	2	3
Milking	0 h	1–29 h	30–49 h	50+ h
Feeding	0 h	1–24 h	25–54 h	55+ h
Herd Health	0 h	1–9 h	10–29 h	30+ h
Maintenance	0 h	1–4 h	5–14 h	15+ h
Fieldwork	0 h	1–24 h	25–54 h	55+ h

	Total Time in Task Score		
Total PPE Score	**1-9 Hours (1)**	**10-29 Hours (2)**	**30+ Hours (3)**
All Necessary PPE Used (1)	LOW (2)	LOW (3)	MODERATE (4)
Some Necessary PPE Used (2)	LOW (3)	MODERATE (4)	HIGH (5)
No Necessary PPE Used (3)	MODERATE (4)	HIGH (5)	HIGH (6)

Figure 1. Risk matrix for herd health task. Similar matrices were developed for each task and the scores summed for the overall risk score.

variables, including time in task and PPE use, were also calculated.

A directed acyclic graph (DAG) modeling exposure outcome relationships was created to guide inclusion of variables in a multivariate regression analysis. Multivariate regression was run with bovine dander specific IgE levels as the dependent variable and risk matrix scores, years spent working with animals, and years of schooling as independent variables. Because the IgE data were continuous, and with a large number of values below the limit of detection, a Tobit regression was performed with the limit of IgE detection of 0.1 kU/L set as the value for left censored data. This analysis was performed using the censReg package in R.[18]

Results

Demographics

All but one participant was male, and the average age of participants was 37.2 years (Table 2). On average, participants completed 8.5 years of school and had worked with cows for 11.9 years. Though only one participant reported ever having had respiratory problems, three participants reported they had been diagnosed with asthma (8.3%), and five participants reported they usually had a cough (13.9%). In addition, four participants (11.8%) reported they had ever had allergies or immune problems. Seven participants (19.4%) had an elevated bovine IgE levels.

Contact with animals

Self-reported contact with various animal byproducts is reported in Table 3. The majority of participants self-reported they always have contact with feces, with only 6.1% reporting they never have contact with feces. While most participants also reported they always have contact with milk (52.9%), 17.6% reported they never have contact with milk. 28.2% of participants reported they always have contact with urine, and 42.4% reported they always have contact with other animal fluids. A higher proportion reported always having contact with blood (17.6%) than animal flesh (11.8%).

Table 2. Demographics of healthy dairy worker participants in this analysis.

	Count (%)
Years Worked with Cows (*n* = 34)	
Mean (SD)	11.9 (7.13)
Years of School Completed (*n* = 34)	
Mean (SD)	8.50 (3.01)
Age (*n* = 34)	
Mean (SD)	37.4 (7.61)
Gender (*n* = 36)	
Male	35 (97.2%)
Female	1 (2.8%)
Ever Had Respiratory Problems (*n* = 35)	1 (2.8%)
Ever Had Allergies or Immune Problems (*n* = 35)	4 (11.8%)
Ever Diagnosed with Asthma (*n* = 35)	3 (8.3%)
Usually Have a Cough (*n* = 35)	5 (13.9%)

Table 3. Participant self reports of contact with animal byproducts.

	Always	Often	Sometimes	Rarely	Never
Blood (*n* = 34)	6 (17.6%)	2 (5.9%)	11 (32.4%)	4 (11.8%)	11 (32.4%)
Urine (*n* = 34)	13 (38.2%)	3 (8.8%)	12 (35.3%)	2 (5.9%)	4 (11.8%)
Feces (*n* = 33)	23 (69.7%)	2 (6.1%)	5 (15.1%)	1 (3.0%)	2 (6.1%)
Animal Flesh (*n* = 34)	4 (11.8%)	1 (2.9%)	9 (26.5%)	5 (14.7%)	15 (44.1%)
Milk (*n* = 34)	18 (52.9%)	4 (11.8%)	2 (5.9%)	3 (8.8%)	6 (17.6%)
Other Fluids* (*n* = 33)	14 (42.4%)	3 (9.1%)	7 (21.2%)	5 (15.1%)	4 (12.1%)

*Includes saliva and amniotic fluids.

Table 4. Summary of bovine allergen risk matrix scores by presence of elevated anti-bovine dander IgE levels (≥ 0.1 kU/L).

	Mean (SD)	Median [Min, Max]	Missing
Total Score			
Elevated IgE ($n = 7$)	9.00 (3.46)	10.0 [5.00, 15.0]	0 (0%)
Not Elevated IgE ($n = 29$)	7.58 (3.57)	8.00 [0, 16.0]	5 (17.2%)
Overall ($n = 36$)	7.90 (3.54)	9.00 [0, 16.0]	5 (13.9%)
Milking Risk Score			
Elevated IgE ($n = 7$)	1.57 (2.15)	0 [0, 5.00]	0 (0%)
Not Elevated IgE ($n = 29$)	1.93 (2.02)	2.00 [0, 5.00]	1 (3.4%)
Overall ($n = 36$)	1.86 (2.02)	2.00 [0, 5.00]	1 (2.8%)
Herd Health Risk Score			
Elevated IgE ($n = 7$)	2.86 (2.73)	4.00 [0, 6.00]	0 (0%)
Not Elevated IgE ($n = 29$)	1.52 (2.06)	0 [0, 5.00]	2 (6.9%)
Overall ($n = 36$)	1.79 (2.24)	0 [0, 6.00]	2 (5.6%)
Feeding Risk Score			
Elevated IgE ($n = 7$)	0.571 (1.51)	0 [0, 4.00]	0 (0%)
Not Elevated IgE ($n = 29$)	1.39 (2.28)	0 [0, 6.00]	1 (3.4%)
Overall ($n = 36$)	1.23 (2.16)	0 [0, 6.00]	1 (2.8%)
Maintenance Risk Score			
Elevated IgE ($n = 7$)	2.86 (2.34)	3.00 [0, 6.00]	0 (0%)
Not Elevated IgE ($n = 29$)	2.38 (2.40)	2.50 [0, 6.00]	3 (10.3%)
Overall ($n = 36$)	2.48 (2.36)	3.00 [0, 6.00]	3 (8.3%)
Fieldwork Risk Score			
Elevated IgE ($n = 7$)	1.43 (2.51)	0 [0, 6.00]	0 (0%)
Not Elevated IgE ($n = 29$)	1.41 (2.14)	0 [0, 6.00]	2 (6.9%)
Overall ($n = 36$)	1.41 (2.18)	0 [0, 6.00]	2 (5.6%)

Risk scores and IgE levels

The average total risk matrix score for participants was 7.9, with a range of 0 to 16 (Table 4). Those with elevated IgE had a mean total score of 9.0 compared to 7.6 for those without elevated IgE. The lowest task specific risk matrix scores were for feeding (mean = 1.2) and fieldwork (mean = 1.4). 66.7% ($n = 24$) of participants reported performing only one or two tasks. All tasks except for milking had a range of risk scores from 0 to 6, indicating a wide range of PPE usage and time spent in task. For milking, the scores ranged from 0 to 5. The only task with a more than 1 point difference in average risk matrix score between those with and without elevated IgE was herd health. Those with elevated IgE had a mean score of 2.86 (median = 4, range = 0–6), compared to a mean score of 1.52 (median = 0, range = 0–5) for those without elevated IgE.

After controlling for years spent working with cows and years of schooling, there were no statistically significant associations between IgE levels and bovine allergen risk matrix scores (Table 5). However, for the task of herd health, a one-point increase in the bovine allergen risk matrix score was associated with a 1.42 kU/L increase in anti-bovine IgE ($p = .08$).

Discussion

This study of risk in dairy workers demonstrates the feasibility of creating job risk matrices to study the health effects of exposure to bovine allergens. A trend was observed between higher risk scores and the level of bovine IgE, although this trend did not achieve statistical significance.

Many of the dairy workers in this study did not have levels of anti-bovine IgE above the limit of detection, despite working with cows for more than a decade on average. Given the long length

Table 5. Coefficient estimates for difference in IgE (kU/l) associated with risk matrix scores using Tobit regression censored at 0.1 kU/l.

Task	Estimate*	95% Confidence Interval	p-value
Overall Risk Matrix Score	0.27	−0.95, 1.49	0.67
Milking Score	−0.73	−2.78, 1.32	0.48
Herd Health Score	1.42	−0.16, 3.00	0.08
Feeding Score	−1.15	−3.49, 1.19	0.34
Maintenance Score	−0.24	−2.05, 1.57	0.80
Fieldwork Score	−0.25	−2.31, 1.80	0.81

*Controlling for years spent working with cows and years of schooling.

of time spent working with cows, this may suggest the presence of healthy worker bias, where workers who develop elevated IgE and related allergic symptoms change jobs and are no longer working with cows.

Regression results indicate a suggestive positive association between performing herd health tasks, such as reproductive management and administering vaccines and medical treatments, and anti-bovine IgE levels. This could be because the tasks performed during herd health generate more allergens, or it could be due to increased exposure to bovine allergens when performing herd health activities due to frequent close interactions with cows. This finding is in line with findings from the Agricultural Health Study, which found performing veterinary procedures daily was associated with increased odds of wheeze.[2] However, that study also found increased odds of wheeze associated with milking cows, which was not identified here, possibly due to the smaller sample size in this study.[2]

These findings are also consistent with other studies that have found an elevated risk of asthma among farm workers. However, dairy workers are exposed to a diverse mix of respiratory exposures, including fecal matter, cow dander, urine, plant material, bacteria, and fungi.[19,20] Many studies have focussed primarily on endotoxins and organic dust broadly as exposures and self-reported symptoms as outcomes. Total dust measurements do not necessarily correlate well with levels of bovine allergen.[21] This can make it more difficult to associate individual exposures with individuals' health outcomes.

This means limited research has isolated allergic outcomes or exposures. A study in Sweden found asthma in farmers is often non-IgE mediated.[22] This is supported by research by Schlünssen et al., who found that although there were levels of bovine allergen as high as 203,831 $\mu g/m^2$ in some dairy stables, no dairy farmers were positive via skin prick tests for bovine dander.[8] However, research in Finland indicated cow dander is the most common cause of occupational asthma and rhinitis in cattle farmers and an important cause of eczema.[23] Hinze et al. also found that concentrations of cow hair-specific IgE were correlated with cow hair allergen levels in the homes of farmers with asthma.[24] Though cattle-specific IgE was not measured, a study of German farmers with suspected allergic airway disease related to cattle also found sensitization to cattle via a skin prick test in 95% of the cases.[25] In the Agricultural Health Study, Hoppin et al. found exposure to dairy cattle among farmers was associated with 3.84 times greater odds of wheeze among those who had atopy and asthma but only 1.28 times greater odd of wheeze among those without atopy and asthma.[2]

A recent study of individuals diagnosed with cow epithelium allergy found that the most commonly reported symptoms were rhinoconjunctivitis and bronchial asthma.[26] The majority of sera samples showed reactivity to a protein identified as likely being Bos d2, which is present in the saliva, dander, and urine from cattle.[26] However, no investigation was carried out to assess exposures associated with this sensitization. At an animal blood processing facility, employees were divided into three exposure categories based on job type.[27] The percentage of individuals who were IgE positive for bovine and porcine plasma proteins increased with increasing exposure.[27] Although this finding is broadly consistent with the findings presented here for herd health tasks, it is unclear how well these findings would translate to a farm environment. Thus, more work is needed to clarify the association between allergen exposure, IgE levels, and health outcomes on dairy farms. Future research which measures allergens in the air and on surfaces utilizing environmental and personal sampling methods in addition to testing participant IgE levels would help with this.

Limitations and strengths

One limitation of this study was the relatively small sample size and the small number of participants with IgE levels above the limit of detection. This limited the power of the analysis to detect an association. However, these findings do suggest more research is needed to evaluate these relationships in larger and more diverse samples. Ideally, this analysis would have included IgE levels from later time points in the HDW study to further strengthen the findings and look for changes in IgE over time. However, due to sample availability and participant attrition, this was not possible. Though the detection of elevated IgE levels does not guarantee the presence of symptoms, or the diagnosis of allergy, IgE is essential to a type I allergic response and indicates exposure to the antigen in question.[28,29] Thus, it can be an informative marker of exposure and suggests the presence of allergic illness. Though the risk matrix used here is individual specific, it was not validated with primary monitoring, and the survey underlying the matrix was subject to recall bias and social desirability bias, which may lead participants to over-report PPE use. This may lead to underestimations of exposure. However, we would not expect these survey related biases to vary between those with and without elevated IgE levels.

Despite these limitations, this study contributes to the limited literature on the association between exposure to bovine allergens and IgE levels in dairy workers, a biologically relevant outcome that is understudied compared to symptomatic measures of illness. The use of a semi-quantitative risk matrix also allows a more formalized conception of the risk of exposure compared to other approaches. Given the current interest in assessing dairy worker exposure and risk related to avian influenza, the development of this matrix also suggests a framework for developing risk characterizations for other respiratory exposures, including infectious agents.

Conclusion

Though this analysis did not identify a statistically significant association between IgE levels and exposure to bovine allergen in the dairy environment, results suggest there may be a positive association between performing herd health tasks and having elevated IgE levels. Further work to more directly measure exposure to relevant antigens and other irritants can help to elucidate this relationship and its potential association with illness among workers.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

All data used in this analysis are available from the authors upon reasonable request.

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