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ORIGINAL ARTICLE

Industrial hygiene assessment of reticuloendotheliosis viruses exposure in the poultry industry

Kyung-Mee Choi · Eric S. Johnson

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Abstract
Objectives Reticuloendotheliosis viruses (REV) are a group of retroviruses like avian leukosis/sarcoma viruses (ALSV) that naturally infect and cause cancers in chickens. We recently found that ALSV antibody levels were associated with job tasks in the poultry industry. The objectives of this study are to examine whether a similar association can be found with REV antibody levels and to examine the correlation between REV and ALSV antibody levels.
Methods Relative risk was estimated comparing REV antibody levels of 45 poultry workers with those of 44 controls. The expected mean antibody level was predicted for the association with employment by a generalized linear model. Correlation coefficient was measured between ALSV and REV antibody levels.
Results REV antibody levels were significantly higher in poultry workers than in control subjects and were associated with gender and employment conditions, especially employment duration. The relative risk was significantly higher for some job categories. A significant correlation was observed between REV and ALSV antibody levels, which was strong among poultry workers, but weak among the control subjects.
Conclusion Antibody levels can be validly used to identify certain job tasks associated with high risk of exposure to REV in the workplace, and the practical implication is recommendations for protection at these job tasks. Importantly, in situations where there is exposure to multiple pathogens in the workplace, the analysis of antibody levels of one pathogen may sufficiently represent exposure to the other correlated pathogens. This suggested exposure assessment may hold true for pathogens with a similar route of transmission.

Keywords Exposure assessment · Microbial agents · Antibodies · Poultry workers · Multiple pathogens

K.-M. Choi (✉)
Department of Environmental and Occupational Health Sciences, University of North Texas, Health Science Center, School of Public Health, 3500 Camp Bowie Boulevard, Fort Worth, TX 76107, USA
e-mail: kchoi@hsc.unt.edu

E. S. Johnson
Department of Epidemiology, University of North Texas, Health Science Center, 3500 Camp Bowie Boulevard, Fort Worth, TX 76107, USA

Introduction

Reticuloendotheliosis viruses (REV), avian leukosis/sarcoma viruses (ALSV), and Marek's disease virus are oncogenic viruses that naturally infect and cause cancers and other chronic and acute diseases in chickens and turkeys (Saif et al. 2003). Infection with ALSV is very common in poultry, but it is less frequent with REV. Studies have indicated that poultry workers are at the increased risk of cancer and neurologic diseases (Johnson et al. 2009a, b). Human infection with these agents, including ALSV and REV, occurs occupationally and non-occupationally. In poultry slaughtering and processing plants, infection occurs by inhalation, since air contamination with infectious agents is well known in slaughtering plants. Poultry workers have a high frequency of cuts, scrapes, wounds, and dermatitis from irritant body fluids such as enzymes. These breaches in the skin integrity provide a ready route for these agents to enter the body. Similarly, penetrating wounds from contaminated sharp knives and bone splinters also provide another means of transmission. In a visit by one of us to a slaughtering plant,

it was disclosed that frequently workers drink the blood from animals, thus providing another route of infection. Transmission in the general population is through ingestion of raw or inadequately cooked poultry products including meat and eggs, contact with live birds and their secretions and excrements, and vaccination with contaminated vaccines such as measles, mumps and yellow fever vaccines that are grown in chicken eggs. It is known for example that all batches of measles and mumps vaccines in use in the United States are contaminated with the endogenous form of ALSV (including the infectious variety) (Tsang et al. 1999; Hussain et al. 2003).

The literature is replete with exposure assessment to chemical and physical agents in the workplace (Levy et al. 2006), but it contains little on microbial agents, although it is often necessary to identify workers at high risk of infection. Our recent study (Choi and Johnson 2010) observed that poultry workers performing certain job tasks had higher antibody levels against ALSV than others in the workplace. The purpose of this study is twofold, one is to identify whether there is an antibody association with employment and the other is to determine whether, in workers exposed to multiple pathogens, the antibody analysis of one pathogen can be used to represent exposure to the other pathogens.

Materials and methods

We analyzed REV antibody levels of 45 poultry workers in a chicken slaughtering and processing plant. Blood samples were previously collected in a study by Johnson et al. (1995), and REV antibodies measured using an Enzyme-Linked Immunosorbent Assay (ELISA). The study was approved by the Human Subjects Institutional Review Board of the National Institute of Environmental Health Sciences, National Institutes of Health, which supported the study. The ELISA used in this study was a whole virus-based test for detecting antibody to REV in human sera that was developed by modifying a commercial ELISA kit for detecting REV antibodies in chickens manufactured by IDEXX, Portland, Maine. The kit included a plate of 96-microtiter wells, which have been coated with the virus that was grown in chick embryo fibroblast and extracted from infected cells by detergent treatment before coating of the wells. Polyvalent goat anti-human immunoglobulin conjugated with horseradish peroxidase was added to the wells to detect any reacting antibodies. Each absorbance reading was corrected by subtracting it from the absorbance obtained for the water control. Three separate ELISA tests were conducted on the same serum sample from each individual on different occasions, and the mean absorbance of these three runs was taken as the final ELISA result for the individual. The coefficient of variation of the test for detecting antibodies in chicken serum was $\leq$5%, and the accuracy $\geq$95%; the specificity was 99.51% and sensitivity 100%. These values were not available for use against human sera.

Poultry study participants were recruited by advertizing through the plant workers union that belonged to United Food & Commercial Workers (UFCW) International Union in Washington, DC. Information collected on poultry workers was restricted to name, sex, race, date of birth, duration of employment, and task performed in the plant. Twenty-eight job titles were identified, representing the last jobs held by the poultry workers in the plant. We grouped the job titles into 8 categories based on job descriptions listed in the union and employer contract agreement (Table 1). A control group of 44 subjects was separately sampled from the general population, matched roughly on sex, race, and age. These control subjects were recruited through advertizing in local newspapers. To be eligible as a

Table 1 Description of job categories

Job category	Description
Eviscerator	Worker who draws or pulls the guts out, in the main production line, or while assisting the USDA (United States Department of Agriculture) inspectors, or who pulls the crow, or who maintains, changes, and cleans the machine that pulls guts
Cutup	Line worker who cuts chickens
Cut hearts and liver (machine done)	Worker that cleans, cuts, and separates liver, gizzards and oil bag, or who operates the machine that cuts and cleans hearts and livers
Trimmer	Trimmer (also called deboner) is one who trims chickens
Plant wide	Utility worker or reliever who does everything plant wide, such as knife sharpening, cleanup, stacks and hangs chickens, picks up condemned chickens, checks chickens, trims, washes, and draws chickens
Hang chickens	Workers who hang live chickens or work as fork lift operators who unload crates of live chickens, and set up chickens for hanging
Panners	Workers who take out feathers off chickens
Post evisceration	Wrap giblets and livers, chiller operator, stuffing chickens, and weigh chickens, helps load boxes

control, subjects should not have had a history of having ever worked in a job where exposure to poultry or poultry products occurred.

Nearly all of the study subjects were black except three, and race was not further analyzed. Study subjects were evenly distributed over three age groups for ≤30 year old, 31–40 year old, and ≥41 year old. Employment duration was used as a proxy variable for exposure duration to REV in the plant. By an increment of 10 years of the employment over tertiles of the sample, employment duration was grouped into a short term for ≤10 years, a midterm for 11–20 years, and a long term for ≥21 years. We first compared the distribution of antibody levels between poultry workers and control subjects, and relative risk was estimated. Next, the expected mean REV antibody levels were predicted for poultry workers based on their demographical and employment information by a generalized linear model (McCullagh and Nelder 1989). Then, we identified the association between the antibody levels of poultry workers and their demographical and employment factors. Finally, the non-parametric Spearman correlation between REV and ALSV antibody levels was measured among the poultry workers and control subjects, respectively. All statistical analyses were done using SPSS (release 17.0.2).

Results

Relative risk of poultry workers compared to control population

The distribution of REV antibody levels was significantly different between poultry workers and control subjects (p value 0.008). It was positively skewed among poultry workers, but not skewed among control subjects (Fig. 1).

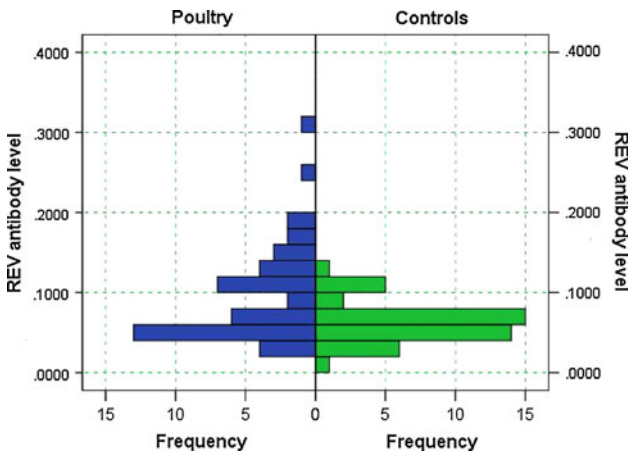

Fig. 1 The distribution of REV antibody levels, for poultry workers on the *left* and control subjects on the *right*

Overall mean antibody level was higher in poultry workers (0.06) than in controls (0.03), and the median for poultry workers, 0.078, was close to the upper quartile level for control subjects, 0.077. Among the poultry workers, the mean antibody level was higher for females than for males, and higher for the age group of 31–40 year old than for the other age groups (Table 2). In contrast, among control subjects, no such patterns were observed, and the mean antibody levels were similar across the different sexes, and age groups (Table 3). The distributions of antibodies for sex and employment duration regarding job category and the distribution of antibodies for sex and employment duration are summarized in Tables 2 and 4, respectively.

We estimated relative risk (RR) for a poultry worker to have a higher level of antibodies than the upper quartile level of control subjects (0.077) while controlling for demographical and employment factors (Table 5). The overall relative risk for poultry workers was significantly high, 2.04. It was higher for female poultry workers ($RR = 2.25$) than for male poultry workers ($RR = 1.54$). It was also significantly high for the age group of 31–40 year old ($RR = 2.35$), but not for the other age groups. The relative risk was significantly high, both for employment lengths of 11–20 years ($RR = 2.18$) and ≥21 years ($RR = 2.12$), respectively. However, it was not significant for the shortest term employment of ≤10 years ($RR = 1.88$). For job categories, the highest relative risk was for "Plant wide" ($RR = 2.91$). The risk was significantly high also for the job categories "Cut heart and liver" and "Cutup" ($RR = 2.67$). For the other jobs, the relative risk was not significant. These findings are similar to those previously observed for ALSV (Choi and Johnson 2010).

Expected mean antibody levels

A generalized linear model was used to predict the mean antibody levels of poultry workers. The variation in the antibody levels of poultry workers was explained by the job and demographical factors as the predictors in a two-way full factorial model. Specifically, gender and employment duration were each significant as the main effect, and job category and employment length was significant together as the interaction effect on the prediction. Job category was not significant as the main effect, but the variation in the antibody levels was more accounted for than by the other model without job category. We observed a significant linear correlation between age in years and employment length in years. This partly explains why age group was not significant in the model that had employment length as a significant factor. All of the two-way interactions between the job and demographical factors were also tested, but they were not significant except the interaction between job category and employment length.

Table 2 Distribution of REV antibody levels in poultry workers for gender and employment length, respectively by job category

Job category		*N*	Mean	Median	SD	Min.	Max.
Eviscerator	Total	8	0.0759	0.0542	0.0415	0.0300	0.1523
	Sex						
	Male	1	0.0527	0.0527	–	0.0527	0.0527
	Female	7	0.0792	0.0550	0.0436	0.0300	0.1523
	Employment length						
	≤11 years	2	0.1028	0.1028	0.0700	0.0533	0.1523
	11–20 years	2	0.0763	0.0763	0.0335	0.0527	0.1000
	≥21 years	4	0.0622	0.0528	0.0356	0.0300	0.1130
Cutup	Total	3	0.0848	0.0780	0.0343	0.0543	0.1220
	Sex						
	Female	3	0.0848	0.0780	0.0343	0.0543	0.1220
	Employment length						
	≤11 years	3	0.0848	0.0780	0.0343	0.0543	0.1220
Cut heart and liver	Total	6	0.1262	0.1347	0.0558	0.0593	0.1973
	Sex						
	Female	6	0.1262	0.1347	0.0558	0.0593	0.1973
	Employment length						
	≤11 years	1	0.0637	0.0637	–	0.0637	0.0637
	11–20 years	1	0.1467	0.1467	–	0.1467	0.1467
	≥21 years	4	0.1368	0.1452	0.0601	0.0593	0.1973
Trimmer	Total	5	0.0809	0.0677	0.0350	0.0460	0.1243
	Sex						
	Female	5	0.0809	0.0677	0.0350	0.0460	0.1243
	Employment length						
	≤11 years	2	0.0612	0.0612	0.0092	0.0547	0.0677
	11–20 years	1	0.1243	0.1243	–	0.1243	0.1243
	≥21 years	2	0.0788	0.0788	0.0464	0.0460	0.1117
Plant wide	Total	11	0.1211	0.1070	0.0767	0.0333	0.3153
	Sex						
	Male	5	0.0894	0.1067	0.0425	0.0333	0.1403
	Female	6	0.1476	0.1190	0.0921	0.0507	0.3153
	Employment length						
	≤11 years	5	0.1458	0.1070	0.0990	0.0597	0.3153
	11–20 years	3	0.0880	0.0507	0.0801	0.0333	0.1800
	≥21 years	3	0.1131	0.1160	0.0106	0.1013	0.1220
Hang chickens	Total	5	0.0646	0.0660	0.0222	0.0370	0.0960
	Sex						
	Male	4	0.0643	0.0620	0.0257	0.0370	0.0960
	Female	1	0.0660	0.0660	–	0.0660	0.0660
	Employment length						
	≤11 years	2	0.0665	0.0665	0.0417	0.0370	0.0960
	11–20 years	2	0.0620	0.0620	0.0146	0.0517	0.0723
	≥21 years	1	0.0660	0.0660	–	0.0660	0.0660

Table 2 continued

Job category		*N*	Mean	Median	SD	Min.	Max.
Panner	Total	2	0.1412	0.1412	0.1652	0.0243	0.2580
	Sex						
	Male	1	0.0243	0.0243	–	0.0243	0.0243
	Female	1	0.2580	0.2580	–	0.2580	0.2580
	Employment length						
	11–20 years	1	0.2580	0.2580	–	0.2580	0.2580
	≥21 years	1	0.0243	0.0243	–	0.0243	0.0243
Post evisceration	Total	5	0.0879	0.0637	0.0511	0.0473	0.1737
	Sex						
	Male	2	0.1105	0.1105	0.0893	0.0473	0.1737
	Female	3	0.0728	0.0637	0.0197	0.0593	0.0953
	Employment length						
	≤11 years	2	0.0615	0.0615	0.0031	0.0593	0.0637
	11–20 years	1	0.1737	0.1737	–	0.1737	0.1737
	≥21 years	2	0.0713	0.0713	0.0339	0.0473	0.0953
Sub-total	Sex						
	Male	13	0.0771	0.0597	0.0449	0.0243	0.1737
	Female	32	0.1062	0.0977	0.0642	0.0300	0.3153
	Employment length						
	≤11 years	17	0.0959	0.0677	0.0656	0.0370	0.3153
	11–20 years	11	0.1130	0.1000	0.0706	0.0333	0.2580
	≥21 years	17	0.0897	0.0953	0.0484	0.0243	0.1973
	Age						
	≤30 year old	14	0.0935	0.0752	0.0578	0.0333	0.2580
	31–40 year old	17	0.1121	0.1130	0.0719	0.0300	0.3153
	≥41 year old	14	0.0847	0.0648	0.0460	0.0243	0.1737
Overall		45	0.0978	0.0780	0.0603	0.0243	0.3153

Unavailable information (e.g., male for "cutup") is not displayed in the table

Table 3 Distribution of REV antibody levels in control subjects

	N	Mean	Median	SD	Min.	Max.
Sex						
Male	12	0.0253	0.0667	0.0600	0.0460	0.1370
Female	32	0.0285	0.0610	0.0612	0.0033	0.1177
Age						
≤30 year old	19	0.0239	0.0678	0.0677	0.0403	0.1370
31–40 year old	14	0.0254	0.0545	0.0477	0.0233	0.1037
≥41 year old	11	0.0358	0.0638	0.0587	0.0033	0.1177
Overall	44	0.0275	0.0626	0.0608	0.0033	0.1370

Table 4 Distribution of REV antibody levels in poultry workers by gender and duration of employment

Employment length	Sex	*N*	Mean	Median	SD	Min.	Max.
≤10 years	Male	6	0.0911	0.1013	0.0370	0.0370	0.1403
	Female	11	0.0986	0.0637	0.0786	0.0533	0.3153
	Total	17	0.0959	0.0677	0.0656	0.0370	0.3153
11–20 years	Male	5	0.0767	0.0527	0.0559	0.0333	0.1737
	Female	6	0.1433	0.1355	0.0712	0.0507	0.2580
	Total	11	0.1130	0.1000	0.0706	0.0333	0.2580
≥21 years	Male	2	0.0358	0.0358	0.0163	0.0243	0.0473
	Female	15	0.0969	0.1013	0.0467	0.0300	0.1973
	Total	17	0.0897	0.0953	0.0484	0.0243	0.1973

Testing for higher than two-way interaction was not carried out due to limited sample size. Thus, the expected mean antibody levels were predicted for poultry workers by the model found with overall significance, that finally included sex, employment length, job category, and interaction between employment length and job category. Table 6 shows the predicted mean antibody levels, controlling for these factors, respectively.

We compared the expected mean antibody levels for the factors in the model, adjusting for multiple comparisons by

Table 5 Relative risks for higher antibody levels in poultry workers than the upper quartile antibody level of control subjects (0.077)

	RR	95% CI lower	95% CI upper
Sex			
Male	1.54	0.65	3.63
Female	2.25[a]	1.24	4.08
Age			
≤30 year old	2.00	0.96	4.16
31–40 year old	2.35[a]	1.23	4.50
≥41 year old	1.71	0.78	3.79
Employment length			
≤10 years	1.88	0.92	3.86
11–20 years	2.18[a]	1.04	4.59
≥21 years	2.12[a]	1.07	4.18
Job category			
Eviscerator	1.50	0.54	4.20
Cutup	2.67[a]	1.03	6.89
Cut hearts and liver (machine done)	2.67[a]	1.24	5.72
Trimmer	1.60	0.49	5.26
Plant wide	2.91[a]	1.55	5.45
Hang chickens	0.80	0.13	4.97
Panner	2.00	0.46	8.76
Post evisceration	1.60	0.49	5.26
Overall	2.04[a]	1.14	3.67

[a] Denotes that 5% level of asymptotic sig (2-sided) by Pearson Chi-Square test

the Bonferroni correction at the overall significance 0.05 (Kleinbaum et al. 1998). Significant differences were found between genders and between employment durations (Table 7). The expected mean antibody level was significantly higher by a difference of 0.07 for females compared with males (p value 0.000). Also, the expected mean level was significantly higher by a difference of 0.04 for the midterm employment of 11–20 years versus the short-term employment of ≤10 years (p value 0.028), and by a difference of 0.05 versus the long-term employment of ≥21 years (p value 0.004). Among the job categories, "Plant wide" was expected to have the highest mean antibody level, followed by "Post evisceration". The job category "Trimmer" had the lowest expected mean antibody level. No other significant mean differences were observed.

Correlation between REV and ALSV antibody levels

We measured the correlation between REV and ALSV antibody levels by Spearman's coefficient (Mood et al. 1974) using the log transformed values (Fig. 2). The overall correlation was higher among poultry workers,

Table 6 The expected mean REV antibody levels predicted by a generalized gamma linear model, controlled for the factors of the model, respectively

	Mean	SE	95% Wald confidence interval	
			Lower	Upper
Sex				
Male	0.0433	0.0091	0.0256	0.0612
Female	0.1142	0.0126	0.0894	0.1389
Employment length				
11–20 years	0.0619	0.0084	0.0454	0.0783
≤10 years	0.1060	0.0155	0.0756	0.1363
≥21 years	0.0531	0.0077	0.0381	0.0681
Job category				
Eviscerator	0.0563	0.0103	0.0360	0.0766
Cutup	0.0522	0.0150	0.0228	0.0817
Cut hearts and liver	0.0669	0.0173	0.0329	0.1008
Trimmer	0.0520	0.0129	0.0267	0.0773
Plant wide	0.0924	0.0131	0.0668	0.1181
Hang chickens	0.0762	0.0161	0.0449	0.1076
Panner	0.0792	0.0244	0.0313	0.1271
Post evisceration	0.0898	0.0185	0.0536	0.1260
Job category for employment length[a]				
Eviscerator for ≤10 years	0.0634	0.0214	0.0213	0.1054
Eviscerator for ≥21 years	0.0383	0.0099	0.0189	0.0577
Eviscerator for 11–20 years	0.0735	0.0227	0.0290	0.1181
Cutup for ≤10 years	0.0522	0.0150	0.0228	0.0817
Cut heart and liver for ≤10 years	0.0392	0.0180	0.0040	0.0745
Cut heart and liver for ≥21 years	0.0843	0.0218	0.0415	0.1270
Cut heart and liver for 11–20 years	0.0904	0.0414	0.0093	0.1715
Trimmer for ≤10 years	0.0377	0.0128	0.0127	0.0627
Trimmer for ≥21 years	0.0486	0.0164	0.0163	0.0808
Trimmer for 11–20 years	0.0766	0.0351	0.0078	0.1454
Plant wide for ≤10 years	0.1731	0.0363	0.1020	0.2443
Plant wide for ≥21 years	0.0697	0.0201	0.0304	0.1090
Plant wide for 11–20 years	0.0654	0.0170	0.0321	0.0987
Hang chickens for ≤10 years	0.1079	0.0365	0.0363	0.1795
Hang chickens for ≥21 years	0.0407	0.0186	0.0042	0.0772
Hang chickens for 11–20 years	0.1006	0.0341	0.0339	0.1674
Panner for ≥21 years	0.0395	0.0181	0.0040	0.0749
Panner for 11–20 years	0.1590	0.0728	0.0163	0.3017
Post evisceration for ≤10 years	0.0379	0.0128	0.0128	0.0630
Post evisceration for ≥21 years	0.0678	0.0209	0.0267	0.1088
Post evisceration for 11–20 years	0.2818	0.1291	0.0289	0.5348
Overall	0.0703	0.0066	0.0575	0.0832

[a] Unavailable information (e.g., "Cutup" for employment length greater than 10 years) is not displayed in the table

Table 7 The comparisons found significant in the expected mean antibody levels among the poultry workers, adjusted by the Bonferroni correction at the 0.05 level

(I)	(J)	Mean difference (I−J)	SE	*df*	Bonferroni sig.	95% Wald confidence interval for difference	
						Lower	Upper
Sex							
Male	Female	−0.0708	0.0187	1	0.000	−0.1074	−0.0342
Employment length							
≤10 years	11–20 years	−0.0441	0.0170	1	0.028	−0.0847	−0.0035
11–20 years	≥21 years	0.0529	0.0166	1	0.004	0.0131	0.0927

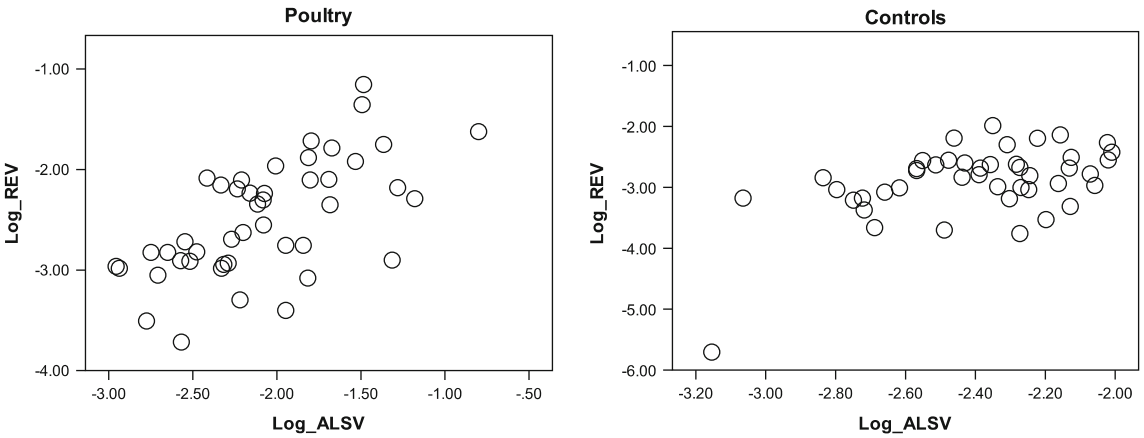

Fig. 2 Correlation in the log transformed antibody levels between ALSV and REV among poultry workers and control subjects, respectively

0.64 (*p* value 0.000), than among control subjects, 0.40 (*p* value 0.007). Among the poultry workers, the correlation was significant for both males and females, 0.58 (*p* value 0.039) and 0.63 (*p* value 0.000), respectively. The correlation was significantly high only for the age group of 31–40 years old, 0.85 (*p* value .000), and not significant for the other age groups. The correlation was significantly high for each of the three job categories, "Evisceration", 0.88 (*p* value 0.004), "Cut heart and liver", 0.94 (*p* value 0.005), and "Post evisceration", 0.90 (*p* value 0.037). It was not significant for the other jobs. In contrast, among control subjects, the correlation was generally weak (i.e., low), and it was significant only for females, 0.35 (*p* value 0.047). As observed for poultry workers, the correlation among control subjects was significantly high, also only for the age group of 31–40 years old, 0.68 (*p* value 0.007).

Discussion

We analyzed for the first time ever, the association between REV antibody levels and employment characteristics in poultry workers. Also, for the first time, this study identified a correlation based on antibody levels between two pathogens (ALSV and REV) in the poultry industry. Our findings indicate that poultry workers are expected to be twice as likely to have higher REV antibody levels than the upper quartile antibody level of control subjects. The higher antibody levels observed among female poultry workers indicate that the gender difference is occupationally related and is more likely due to differences in jobs held and in duration of employment between males and females (Tables 2 and 4). Employment duration was significant not only by itself, but also together with job category in the estimation of mean REV antibody levels. Poultry workers in certain jobs appeared to be significantly associated with high risk of exposure to REV, namely "Cut heart and Liver", "Cutup", and "Plant wide". This indicates that antibody levels can be useful in identifying certain job tasks with high risk of exposure to infectious agents in the workplace and that the practical implication is the recommendations for protection at these tasks.

Although we observed interaction effects, it was limited by small sample size, and it should be studied further in larger studies. REV antibody levels were strongly correlated with ALSV antibody levels among poultry workers, but the correlation was weak among control subjects. This suggests that, in a workplace where exposure to a large number of various microorganisms occurs, i.e., different kinds of viruses, bacteria, protozoa, fungi, helminths, etc.,

the study of exposure to one of these agents may possibly adequately describe exposure to the other agents. In spite of its limited sample size, overall, the study consistently suggested that the analysis of antibody levels can be used as an industrial hygiene tool to assess exposure to multiple microorganisms in the workplace, if their route of transmission is similar.

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Conflict of interest The authors declare that they have no conflict of interest.

References

Choi K-M, Johnson ES (2010) Industrial hygiene exposure assessment by antibody levels—exposure to avian leukosis/sarcoma viruses in poultry industry. Ann Ind Hyg (in review)

Hussain AI, Johnson JA, da Silva-Freire M, Heneine W (2003) Identification and characterization of avian retroviruses in chicken embryo-derived yellow fever vaccines. Investigation of transmission to vaccine recipients. J Virol 77:1105–1111

Johnson ES, Nicholson LG, Durack DT (1995) Detection of antibodies to avian leukosis/sarcoma viruses (ALSV) and reticuloendotheliosis viruses (REV) in humans, by enzyme-linked immunosorbent assay (ELISA). Cancer Detect Prev 19:394–404

Johnson ES, Yau CL, Zhou Y, Singh KP, Ndetan H (2009a) Mortality in the Baltimore union poultry cohort : non-malignant diseases. Int Arch Occup Env Health. doi:10.1007/s00420-009-0478-6

Johnson ES, Zhou Y, Yau CL, Prabhakar D, Preacely N (2009b) Mortality from malignant diseases-update of the Baltimore union poultry cohort. Cancer Causes Control. doi:10.1007/s10552-009-9452-6

Kleinbaum DG, Kupper LL, Muller KE, Nizam A (1998) Applied regression and other multivariable methods, 3rd edn. Duxbury Press, Pacific Grove

Levy BS, Wegman DH, Baron SL, Sokas RK (2006) Occupational and environmental health. Recognizing and preventing disease and injury, 5th edn. Lippincott Williams & Wilkins, Philadelphia

McCullagh P, Nelder JA (1989) Generalized linear models, 2nd edn. Chapman Hall, London

Mood AM, Graybill FA, Boes DC (1974) Introduction to the theory of statistics, 3rd edn. McGraw Hill, New York

Saif YM, John Barnes H, Fadly AM, Swayne D, Glisson JR (2003) Diseases of poultry, 11th edn. Iowa State Press, Iowa

Tsang SX, Switzer WM, Shanmugam V et al (1999) Evidence of avian leucosis virus subgroup E and endogenous avian virus in measles and mumps vaccines derived from chicken cells: investigation of transmission to vaccine recipients. J Virol 73:5843–5851