

Exposure of Laboratory Animal Care Workers to Airborne Mouse and Rat Allergens

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Urine of rats and mice is the main source of allergenic proteins that can enter the respiratory tract of laboratory animal care workers. Little is known about the levels and determinants of these exposures in the United States. We investigated the relationship between activities in animal facilities and levels of personal exposure to allergen by collecting personal breathing zone dust samples from 7 caretakers during full workdays for 1 wk. Mice and rat urinary allergens in inhalable dust were quantified via immunoassay. The activities of the sampled workers were observed, and the methods of preventing exposure to allergens were recorded. Mouse urinary allergen was detected in 20 of 39 measurements, yielding a geometric mean of 0.8 ng/m³ with a maximum of 24 ng/m³. Washing and cleaning cages and the number of mice handled daily were the most important determinants of personal exposure to mouse urinary allergen, as identified by using multiple linear regressions that explained 51% of total variance. Personal exposures to mouse urinary allergen were associated with day-to-day variation of tasks rather than characteristics of workers. Where potential for personal exposure is the highest, protective measures (N95 masks and cage dumping stations) appeared to be used, as is appropriate. Rat urinary allergen was detected in 4 of 39 measurements; detectable concentrations were between 0.8 and 39 ng/m³. Only persons who handled rats were exposed to rat urinary allergen. The current findings are valuable for establishing exposure levels against which comparisons of improvement or deterioration of personal exposures can be made.

Abbreviations: MUA, mouse urinary allergen; RUA, rat urinary allergen.

The National Institute of Occupational Safety and Health estimates that the number of workers exposed to animals or animal products ranges from 40,000 to 2 million.¹⁸ Allergens can be found in dander, hair, saliva, urine, and serum of the laboratory animals.¹⁴ However, in workplace settings, urine is the main source of allergenic proteins from rats and mice.^{4,7} These proteins in urine can become aerosolized which allows it to enter into the respiratory tract and lungs of persons working with laboratory animals. Animal allergens are carried on a wide range of particle sizes, some of which can remain airborne for extended periods of time to cause 'bystander exposure' in a workplace, whereas others are too large to be inhaled.¹⁴ Developing allergy is a common occupational hazard for workers exposed to laboratory animals. Such workers are at risk for developing occupational asthma, contact dermatitis or urticaria, rhinitis, and conjunctivitis, with components of the urinary protein of rats and mice being the major allergens involved in these illnesses.³² However, information regarding exposure limits and risk assessment models for these workplaces is scant.

Exposure to rodent allergens can be reduced in many ways, including through the use of engineering and administrative controls and personal protective equipment.^{10,16} Several studies have measured the airborne urinary allergens at fixed locations in animal rooms.^{22,31} Fixed-location sampling studies have examined the effects of caging systems,^{8,9,17,25,29} bedding characteristics,¹⁵ and room air flow and relative humidity⁴ in reducing urinary allergens at the room level. One study demonstrated the effectiveness of personal protective equipment

though application of innovative personal sampling methods that place sampling media in the nostril, behind a respirator.²⁷

Sampling at the room level is limited in its ability to determine the actual exposure of personnel to urinary allergens. Using portable personal air sampling devices, some authors measured rat urinary allergens (RUA) and showed that exposure level was related to the tasks performed, with 3 to 10 times higher concentrations during tasks that dealt with 'active animals' (feeding, cleaning, handling; approximately 10 to 20 ng RUA/m³) compared with 'inactive animals' (surgery, euthanasia).⁵ Another group noted that personal exposures were 10-fold higher than concentration detected from stationary area samples of air even if collected in close proximity to studied tasks.⁵ Several other studies briefly described below that used personal air sampling have shown that exposure intensity varies with the facility, type of job, type of tasks performed and their length. These studies focused on shifts when personnel performed a specific task or collected samples over short periods of time during task specific activities.^{11,12,20,21,30}

In many animal facilities, animal care personnel are not limited to a single activity during a shift but instead perform a variety of tasks which contribute in varying degrees to total allergen exposure. For example, animal technicians and caretakers had elevated RUA and mouse urinary allergen (MUA) exposure compared with scientific staff and supervisors.¹¹ For both allergens, cleaning cages and moving animals to new cages was associated with the highest personal exposures; lower exposures were seen with feeding and handling animals.¹² Washing cages was the lowest-exposure task; the ranges of geometric means between highest- and lowest-exposure tasks were 8 ng/m³ for RUA and 25 ng/m³ for MUA.¹² In addition, exposure levels during the highest-exposure task varied widely, on average, among the 6 laboratories that were compared, indicating that specifics

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aspects of the task, equipment, and work practices at individual facilities are influential.¹² Subsequent work by the same group revealed that personal exposures to various aeroallergens at 7 facilities were positively correlated with the numbers of animals in rooms.¹¹ Another study found a strong association between density of mice in the room and MUA exposures.²¹ One study used personal air sampling and data from a work record sheet (completed by animal care personnel) in an ANOVA model to identify tasks that explained 63% of the variation in rat urinary allergens in personnel during a full work shift.²⁰ Other researchers found that airborne MUA exposures were the highest during manual emptying and changes of cages and handling of animals and provided evidence that various ventilation and automation measures can effectively reduce exposures during these tasks.³⁰ Another study identified cage-cleaning tasks as being associated with the highest exposure intensity (approximately 500 $\mu\text{g RUA}/\text{m}^3$), with exposure intensity 4-fold higher than during handling rats or indirect contact with the animals; the lowest-exposure task was washing cages (approximately 25 $\mu\text{g RUA}/\text{m}^3$).²⁰ Although the comparison of actual concentrations across studies is hampered by interassay differences, the relative rankings of tasks within studies allows some generalizations to be drawn.

Research on the levels and determinants of personal exposure to aeroallergens among laboratory animal workers has been carried out predominantly in Europe, with scarce and indirect data on corresponding exposures in the United States, although recent work suggests that laboratory animal workers in North Carolina are at increased risk of laboratory animal allergy and recommends limitation, insofar as possible, of the hours per week of exposure to laboratory animals.⁶ The same study found exposure-response associations between duration of work with rats or mice and species-specific allergy symptoms.⁶ In the current study, we investigated the relationship between animal caretaker tasks and full-shift personal exposures to airborne RUA and MUA in 2 laboratory animal research facilities in Philadelphia, PA.

Materials and Methods

The research protocol was reviewed and approved by Drexel University Institutional Review Board and the Drexel University IACUC in accordance with applicable federal regulations.

Laboratory animal care workers. The sample for this study comprised 4 animal care staff members (3 male, 1 female) from facility 1 and 3 animal care staff members (1 male, 2 female) from facility 2. In addition, 2 students not permanently employed at facility 1 were included because they were at work on the days of exposure measurements and performed tasks ordinarily assigned to permanent staff. This situation arose because one of the workers was on restrictive duty, and the students performed this worker's cage-changing tasks. Both facilities each have a single animal care staff member ('cage washers') whose sole task is to dump cages into cage-dumping stations, store the cages on a rack, spray the inside of the cages to dislodge some of the larger detritus, and run the rack through the cagewash machine. Cages subsequently were allowed to dry and were restacked for future use. Although other animal care staff members sometimes assisted with the cage-washing task, their primary tasks include unpacking and caging new animal deliveries, daily observations, feeding and watering animals, moving cages, autoclaving, changing cages, and sanitizing rooms once monthly. Sanitizing is the only task that is performed at regularly scheduled times; the rest of the tasks are performed as need arises. During the current study, shipments of animals

arrived and required unpacking 2 or 3 d each week, depending on the vendor and species.

Subjects were recruited via consent letter for their willingness to participate in the research, a voluntary task that they could refuse. The recruitment letter clarified to potential participants that they were allowed to withdraw from the study at any time and that they could refuse to provide any information. In addition, animal care staff members were informed of the aims of the research. Information on age, sex, ethnicity, years working at the facility, and typical duties was recorded. Use of personal protective equipment was noted. Most animal care staff members routinely wore scrubs, a disposable isolation gown, and gloves but typically no mask, although some staff members sometimes wore surgical or isolation masks during work. N95 respirators were worn by workers when dumping cages, part of cage-washing task. In barrier rooms, it was mandatory for subjects to wear a cap, mask, gloves, disposable isolation gown, and shoe covers.

Description of the facilities. During the time of our research, facility 1 housed 460 mouse cages (3 to 5 mice per cage; total, 1380 to 2300 mice), 26 rat cages (2 rats per cage; total, 52 rats), 5 to 6 rabbits, and 3 swine each week. Facility 2 housed 7 cats, 296 mouse cages (3 to 5 mice per cage; total, 888 to 1480 mice), and 237 rat cages (2 rats per cage; 474 rats). All mice were housed in isolation caging (MicroVent, Allentown, Allentown, NJ) on a ventilated rack with HEPA airflow. The ventilation units supplying these cages provided 60 air changes hourly and are serviced and certified annually. Whereas all mice were housed in these cage systems, all rabbits, cats, and rats were housed in static open-air cages. In addition, the ventilation in each holding room was supposed to have provided an air exchange of 10 to 15 air changes hourly, but this exchange rate was not verified during data collection. Cages were changed at least once weekly for mice, twice weekly for rats, and thrice weekly for rabbits. Facility 1 used corncob bedding, and facility 2 used hardwood chips and paper chips (AlphaDry, Shepherd Specialty Papers, Kalamazoo, MI) for rats after surgery and hardwood chips and corncob bedding for other animals. In the animal housing rooms, cages were opened for changing and animal handling within an animal transfer station (ATS5, Allentown) that was equipped with HEPA filter that is 99.99% efficient at filtering particles of 0.3 μm and smaller when placed under the hood. These change stations are serviced and certified annually. Not all rooms at facility 1 had animal transfer stations, whereas all rooms at facility 2 had them. Dirty cages were transferred to the wash room, emptied into a cage-dumping station (facility 1: model 3B, Viking Medical, Medford Lakes, NJ; facility 2: BioBubble Bedding Disposal Unit, Clean Room, Ft Collins, CO). The dumping stations were equipped with a HEPA-filtered hood vent and trash can underneath and were serviced and certified annually.

Collection of personal inhalable dust samples. Particulate samples from personal breathing zones were collected on 37-mm-diameter sampling cassettes loaded with 0.8- μm pore-size MCE filters with PVC support (Zefon International, Ocala, FL). Samples were collected in the worker breathing zone, outside of any respiratory protective equipment. Sampling devices collected total airborne particulate; the size distribution of the particulate collected was not assessed. Standard personal sampling pumps (Sidepak models 730 and 330, TSI, Shoreview, MN) were used to draw air through the filters. The pumps were calibrated daily to a flow rate of 2.5 L/min at each sampling site immediately prior to sampling. Flow rates were remeasured at the end of sampling. Air flow through sampling apparatus

was measured as an average of 10 readings by a frictionless piston (DC1 Flow Calibrator, BIOS International, Butler, NJ). On sampling days, laboratory animal workers were asked to wear sampling devices for the duration of their work-shifts. The duration of sampling was recorded. We collected 6 field blanks for quality control.

Quantification of allergens. Rat and mouse allergen levels in dust samples were quantified by ELISA, which were performed by a commercial lab that used their own kit (Indoor Biotechnologies, Charlottesville, VA).¹³ The analytical methods were used in prior research and are described in detail in the literature.^{23,24,26,28} Briefly, allergens were extracted by submerging filters in 1 mL buffer (PBS plus 0.05% Tween 20, pH 7.4) in a 15-mL centrifuge tube, rotated for at least 2 h, and then diluted 1:2 into the same buffer. Two-fold serial dilutions of murine and rat allergen standards (Universal Allergen Standards, mus M1 for mouse and rat n1 for rat allergens, Indoor Biotechnologies) in PBS-Tween were used for quantification of filter extracts; mus M1 standard concentrations ranged from 25 to 0.05 ng/mL and rat n1 from 100 to 0.2 ng/mL. Polystyrene microtiter plates were coated with antiMus m 1 polyclonal antibody at 2 µg/mL in 50 mM sodium carbonate-sodium bicarbonate buffer (pH 9.6), 100 µL per well, or with antiRat n 1 monoclonal antibody RUP6 (source) at 1 µg/mL in 50 mM sodium carbonate-sodium bicarbonate buffer (pH 9.6), 100 µL per well, overnight at 4 °C. After the plates were washed 3 times with PBS-Tween, they were blocked for 30 min at room temperature with 1% BSA in PBS-Tween (100 µL per well), and again washed 3 times with PBS-Tween. Plates were loaded with 100 µL per well of blank samples, allergen extracts in serial 2-fold dilutions from 1:10 to 1:80, or allergen standard dilutions in 1% BSA in PBS-Tween. Plates were incubated for 1 h at room temperature and then washed 3 times with PBS-Tween. For detection, biotinylated antiMus m1 or antiRat n1 was added at 1000-fold dilution in 1% BSA in PBS-Tween at 100 µL per well. After incubation for 1 h at room temperature, plates were washed and then incubated with 0.25 µg/mL streptavidin-peroxidase (catalog no. S5512, Sigma-Aldrich, St Louis, MO) in 1% BSA in PBS-Tween (100 µL per well) for 30 min at room temperature, followed by 3 washes in PBS-Tween. Plates were developed by adding 1 mM 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid in 70 mM sodium citrate-sodium phosphate buffer (sodium) (pH 4.2) with 0.03% H₂O₂ (100 µL per well). Absorption at 405 nm was read when the OD₄₀₅ reached 2.0 to 2.4. Because the quantification limit and detection limit are the same, practically speaking, we defined this value as the lowest points on the calibration curves and used it in calculations for both RUA and MUA.

Documenting potential determinants of exposure. The activities of the sampled laboratory animal workers were observed throughout the sampling shifts and recorded at 15-min intervals by an investigator (JTG). Whenever a task was performed during any 15-min interval, a checkmark was made on a checklist corresponding to that task and time interval. According to a previous method for the calculation of total duration of tasks from direct observation,³ all tasks performed in a 15-min interval were presumed to be of equal duration. Tasks were defined as cage washing, unpacking and caging new deliveries, feeding animals, watering animals (refilling water bottles), moving cages from one room to another, autoclaving, changing cages (moving animals from dirty cages to clean cages), daily observations (checking cages for injured animals), and work break. At the end of each air sampling day, each sampled animal laboratory worker was interviewed about tasks they had performed that day. In addition, any applicable methods of preventing expo-

sure to allergens (use of personal protective equipment, animal transfer stations, and cage dumping stations) and whether they were used appropriately were recorded each day.

Data analysis. The distribution of each of the exposure measures was examined by using frequency histograms and tested for normality by using Q-Q plots. We anticipated that log-normal distributions would be observed for the exposure measures, necessitating $\log_e$ transformation of the observed exposure measures prior to their entry into simple regression models that related each continuous determinant of exposure (time per task, self-reported exposure scale, number of animals handled) to exposure. Regression residuals were examined for homoscedasticity. For both allergens, values that were below the detectable limit were replaced by using half the limit of detection. Through backward elimination of determinants of exposure (time per task, use of dump and animal transfer stations, number of cages dumped and transfers effected) we arrived at multiple-regression models of exposure that only contained predictors associated with statistically significant ($P < 0.05$) effect estimates. We also considered correlation of measurement among workers in linear mixed-effect models that assumed compound symmetry covariance structure (Proc Mixed in SAS version 9.1, SAS Institute, Cary, NC), but because between-worker variances was not distinguishable from zero, we therefore simplified the analysis by assuming that all measurements were independent. SPSS version 18.0.0 and Excel 2010 (Microsoft, Redmond, WA) software were also used in the data analyses presented.

Results

Sampling took place over 2 wk in March 2011; 1 wk was spent at each facility. The average daily duration of sampling was 8 h for each staff member only 2 h for the 2 students involved. A total of 39 allergen measurements were collected, with as many as 5 daily measurements (Monday to Friday) per subject. There was no association between particle mass collected and content of studied allergens (data not shown but available on request from the authors), and we therefore focus the remaining analysis on the allergen content of the filters.

Personal exposure to MUA varied widely: from less than 0.16 (the limit of detection) to 24.0 ng/m³ (Table 1). The geometric mean for MUA was 0.8 ng/m³, with a large geometric standard deviation of 5.8, suggesting skewed distribution, which can also be seen from the fact that arithmetic mean (3.3 ng/m³) greatly exceeded the geometric mean. Histograms confirmed these conclusions (data not shown).

Table 2 presents the associations between personal exposure to airborne MUA and the use of equipment designed to reduce personal exposure. Tasks associated with wearing an N95 mask had a nearly 5-fold higher personal exposure (geometric mean, 2.5 ng/m³) compared with those of other tasks (geometric mean, 0.6 ng/m³), suggesting that the most protective masks were used appropriately during tasks entailing the highest potential personal exposure. Protective equipment used during washing cages, such as the cage dumping station, was associated with a near 3-fold increase in personal exposure. When animal transfer stations were used, personal exposure was lower on average by approximately 2-fold (geometric mean of 1.3 compared with 0.7 ng/m³) when they were not used. All these estimates were associated with high variability reflected by large geometric standard deviations (4 to 7).

In most cases, the simple linear regressions (Table 3) revealed little correlation between the times spent performing most tasks and airborne MUA concentrations, with correlation coefficients

Table 1. Descriptive statistics of allergen measurements in personal breathing zone (a total of 39 measurements on 9 subjects)

Allergen	No. (%) of nondetects	Geometric mean (ng/m ³)	Geometric standard deviation	Mean (ng/m ³)	75th percentile (ng/m ³)	Maximum (ng/m ³)
Mouse urinary allergen	19 (49)	0.8	5.8	3.3	4.4	24
Rat urinary allergen	35 (90)	0.5	2.9	1.5	0.4	39

Table 2. Mouse allergen concentrations in relation to use of equipment for alleviating exposure in full-shift personal measurements

Equipment	Equipment used?	No. of measurements	No. of persons	Geometric mean (ng/m ³)	Geometric standard deviation
Surgical mask	No	17	7	1.4	5.3
	Yes	22	9	0.6	5.8
N95 mask	No	29	9	0.6	5.5
	Yes	10	3	2.5	4.4
Cage dumping station	No	29	7	0.6	5.2
	Yes	10	2	2.0	6.3
Animal transfer station	No	15	8	1.3	7.1
	Yes	24	8	0.7	5.0

Table 3. Descriptive statistics of duration of tasks and number of animals in association with $\log_e$ (mouse urinary allergen [MUA; ng/m³]) in simple linear regressions

Predictor variable and its distribution			Simple linear regression with $\log_e$ (MUA exposure)				
			Percentile			Estimated slope (95% confidence interval)	Correlation coefficient
	Mean	Standard deviation	25	50	75		
Tasks (min/d)							
Cage wash	100	155	0	0	255	+0.004 (0.001, 0.007)	0.3
Unpacking and cag- ing new deliveries	10	21	0	0	0	+0.01 (−0.01, 0.04)	0.2
Feeding animals	46	36	20	40	61	−0.004(−0.02, 0.01)	0.1
Watering animals	39	35	8	40	58	+0.003 (−0.01, 0.02)	0.1
Moving cages	10	15	0	0	26	+0.02 (−0.01, 0.06)	0.2
Autoclaving	4	20	0	0	0	−0.01 (−0.04, 0.02)	0.1
Changing cages	29	32	0	24	46	+0.01 (−0.01, 0.03)	0.2
Sanitizing rooms	13	38	0	0	0	−0.02 (−0.03, 0.01)	0.3
Daily observations	58	56	0	45	90	−0.01 (−0.02, 0.01)	0.3
Break	91	92	0	60	130	−0.01 (−0.01, −0.002)	0.4
Setup for next days	33	57	0	0	53	−0.01 (−0.02, −0.002)	0.4
No. of animals handled							
Mice	77	160	0	2	80	+0.005 (0.002, 0.008)	0.5
Rats	27	67	0	0	3	−0.005 (−0.01, 0.003)	0.2
Rabbits	1	2	0	0	0	−0.008 (−0.4, 0.3)	0.01
Piglets	1	2	0	0	3	0.1 (−0.2, 0.4)	0.1
Cats	1	3	0	0	0	−0.1 (−0.3, 0.1)	0.1

ranging from 0.1 to 0.4. The highest correlation (although not significant at the nominal 5% level) between these 2 parameters was for time spent moving cages, where slope (in units of $\log_e$ (ng/m³)/min) was found to be +0.02 (95% confidence interval, −0.01 to 0.06). This value may reflect the resuspension of particles in the bedding while cages were moved, causing dust and allergens to be spread through the air. The only associations that appeared to be not due to chance at the conventional significance at the 5% level were washing cages, which was

associated with increased personal exposure (slope, +0.004; 95% confidence interval, 0.001 to 0.007), and tasks associated with being away from animals (break and set-up), which were associated with decreased personal exposure compared with those for other tasks (95% confidence interval, −0.01 to −0.002). Not surprisingly, only the number of mice handled was associated with personal exposure to MUA (slope, +0.005; 95% confidence interval, 0.002 to 0.008), with moderate correlation of 0.5 (Table 3). This association is illustrated in Figure 1: as the

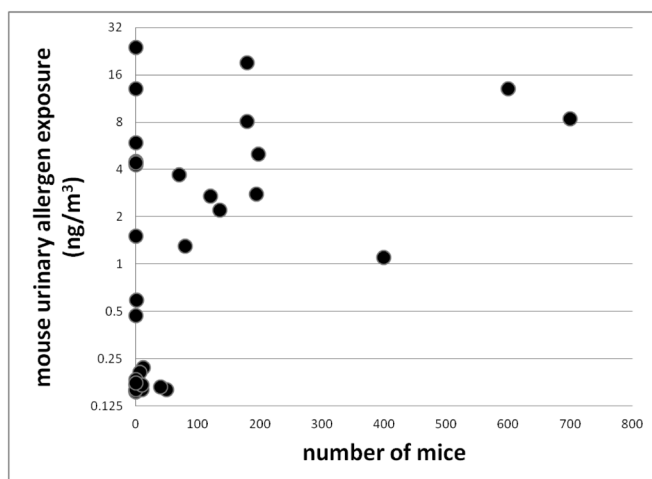


Figure 1. Relationship of the number of animals handled to personal exposure to mouse urinary allergens (personal exposure axis is transformed by using log_e).

number of animals handled increases (horizontal axis), so does the logarithm of MUA exposure (vertical axis).

The selected final multiple linear-regression model of MUA exposure explained 51% of variance (Table 4). The analysis suggests that as the number of mice handled daily increased personal MUA exposure increased. In addition, dumping cages was independently associated with increased exposure to MUA because the majority of animals housed in cages were mice (see descriptions of the facilities in Methods). As the number of cages that were changed daily (Figure 2; horizontal axis) increased, so did the logarithm of MUA exposure (on vertical axis).

Personal exposure to RUA varied widely, from less than 0.3 (the limit of detection) to 39 ng/m³ (Table 1). Only 4 of 39 samples yielded detectable measurements, precluding further statistical analysis. As for MUA, as the number of rats handled daily increased (Figure 3; horizontal axis), so did the logarithm of RUA exposure (vertical axis).

Discussion

Our findings are largely in agreement with assessments performed in comparable workplaces in other countries over the last 20 y. The current findings regarding workers who washed, dumped, or cleaned cages are consistent with other studies that have looked at urinary allergens. In particular, several authors previously found that tasks associated with high exposure were cleaning cages and handing of animals, whereas those with lower exposures were tasks in the animal rooms that did not involve major movement of animals.^{12,19,20,30} An important distinction must be drawn between washing and cleaning cages, given that washing (presumably a wet process that entails dust suppression) was associated with much lower exposures than was cleaning.²⁰ We did not observe the same effect, suggesting that particular attention to wet compared with dry cage cleaning may be warranted when assessing the effectiveness of dust suppression. Our finding of a positive relationship between increased allergen exposure and working with a greater number of rats and mice is consistent with the literature.^{11,19,21} The likelihood of finding detectable animal allergens in the air was directly related to the number and type of animals housed. That is, we studied facilities that primarily house mice (more than twice as many as rats, the next most numerous species), and consequently mouse but not rat urinary allergens were detected most often in the personal breathing zone of the employees.

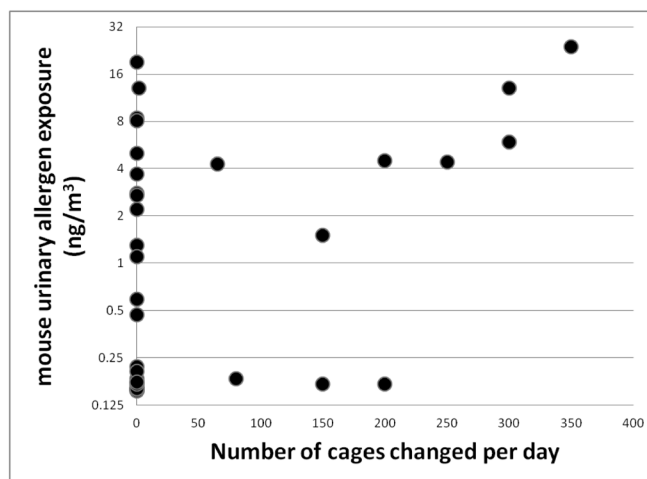


Figure 2. Relationship of personal exposure to mouse urinary allergens to the number of cages changed daily (personal exposure axis is transformed by using log_e).

Several exposure controls are already in place in the 2 facilities we studied, including cage dumping and animal transfer stations at both facilities. In each of these cases, there was no difference in allergen exposure with or without utilization of these stations, suggesting that personal allergen exposure may already be well controlled. In addition, the persons who wash and clean animal cages were in a substantially wetter environment than were the other workers, used cage dumping stations, and always wore N95 masks, indicating that this task may already be a well-protected job. This matter can be studied further by comparison to exposures in a facility that lacks these exposure control measures entirely.

The current study had several limitations. We did not identify any strong predictors of allergen exposures. However, if the exposures at the studied laboratories are as low as reasonably achievable, then we most likely would not identify any important modifiable predictors of exposure levels left beyond random fluctuations of allergen concentrations in the air. In other words, a perfectly controlled environment that has not yet eliminated exposure altogether (by complete isolation of process or elimination of source—which is implausible in the studied setting) will still demonstrate random fluctuations in exposure that cannot be explained by modifiable factors, given the manner in which the facility is operated. This scenario is plausible because a comprehensive set of determinants of exposure was examined in a similar yet poorly controlled setting and explained much of the variability in exposure levels.³ We speculate that as long as personal exposure levels depend on the number of animals handled (as has been shown in all studies in the field), there ought to be room for lowering exposures, because in an ideally controlled setting, working conditions (such as number of animals) would not affect personal exposures; that is, personal exposure would arise only from some general background contamination after the influence of all modifiable sources has been mitigated.

We did not detect any association of personal exposure with duration of tasks. This finding is surprising but may be the consequence of imprecision in determining the duration of tasks; such errors can substantially distort true associations.¹ Conversely, the duration of a task may be less important in the given setting than is the fact that the task was performed, and perhaps the intensity of the source is more important than is the time period over which a source contributed contaminants.

Table 4. Multiple linear-regression model of personal exposure to mouse urinary allergen (dependent variable $\log_e[\text{ng MUA}/\text{m}^3]$)

	Mean (SD)	Median	75th percentile	Maximum	Regression coefficient (slope)	
					Estimate ^a	SE
No. of mice handled daily	77 (160)	2	80	700	0.007	0.001
No. of cages dumped daily	52 (102)	0	65	350	0.01	0.002

All estimates of regression coefficients were selected to have $P < 0.05$.

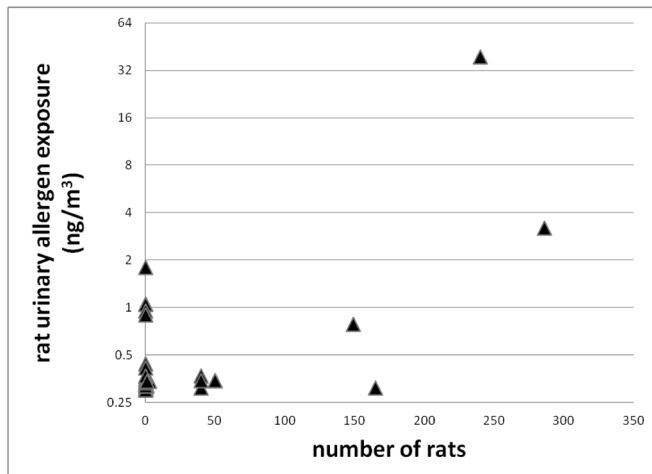
^aintercept = -1.2; SE, 0.3

Figure 3. Relationship of the number of animals handled to personal exposure to rat urinary allergens (personal exposure axis is transformed by using $\log_e$).

into the personal breathing zone. Any recording of duration of tasks (for example, at 5- or 10-min intervals) is subject to the type of error we describe. Some researchers use task diaries to log this information, but diaries are subjective and prone to reporting bias.² An alternative is to videorecord tasks to obtain a more precise estimate of duration, but videography can be exceedingly labor-intensive for the investigators and may be considered invasive by the subjects. Examination of our data did not reveal that the absence or presence of any specific task was an important predictor of exposure. We collected measurements from personal breathing zones but outside of any respiratory protective equipment; therefore, most of our conclusions pertain to potential rather than actual exposures, given that respiratory protection can substantially attenuate personal exposure in the studied setting.²⁷

Measuring of allergens is problematic, and no standard assays exist, thereby making it unadvisable to compare absolute allergen measurements among laboratories. For this reason we do not compare the levels we obtained here with previously published results.

Although the implication of our results on the health of the laboratory animal workers we studied is unknown, our study is important because it enables comparison of worker tasks with their allergen exposure levels in an animal laboratory setting. The resulting baseline data can help evaluate facilities' ongoing efforts to minimize worker exposure to allergens and establish acceptable exposure standards. Future research might include investigating the allergens produced by other animal species, the allergen content of the beddings, measurements behind respiratory protection, studies of dermal exposure, and ongoing exposure surveillance. Another direction is to assess the exposure of researchers, who may have less intense contact with the animals than do the husbandry staff but who contact

animals under less controlled conditions and with fewer exposure control measures in place.

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