Acute Pulmonary Function Change Associated With Work on Large Dairies in California

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Objective: To study whether dairy workers in California have lower baseline and greater cross-shift decrements in lung function than control employees. **Methods:** A cross-sectional study of 210 dairy and 47 control workers who completed questionnaires and spirometry before and after the work shift. **Results:** Dairy work was associated with mean baseline differences of −0.132 L ($P = 0.07$) and −0.131 L ($P = 0.13$) in forced expiratory volume in 1 second and forced vital capacity, respectively, compared with control employees, adjusting for age, height, smoking status, and days back at work since last day off. Dairy work was associated with a mean cross-shift difference of −65.2 mL ($P = 0.02$) and −103.1 mL ($P < 0.01$) in forced expiratory volume in 1 second and forced vital capacity, respectively, adjusting for smoking status and work-shift time. **Conclusions:** Dairy work in California was associated with mild acute airway obstruction. The unclear long-term effect of dairy work in California merits further investigation.

Dairy work has been associated with an increased prevalence of respiratory symptoms, including chronic bronchitis, wheeze, allergies, hypersensitivity pneumonitis, and organic dust toxic syndrome.[1–7] Dairy farming also has been associated with an accelerated decline in the ratio between forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC) and with moderate airway obstruction.[1–3,5] Sufficient exposure to organic particles, specifically endotoxins, may result in dose-dependent organic dust toxic syndrome. The endotoxin content of respirable dust has been associated with decreased FEV_1.[8,9]

Although previous studies have documented the association between dairy work and decrements in respiratory health, the situation in California is distinctive. In 2007, California's dairies had an average herd size of 952 cows.[10] By contrast, the second and third highest-producing dairy states Wisconsin and New York had average herd sizes of 88 and 108 cows, respectively.[10] European dairies had even smaller herds, ranging in size from an average of 35 cows (Belgium) to 78 cows (the United Kingdom).[11] In addition to substantially larger herd sizes, California's dairy facilities have naturally ventilated barns or open corrals in contrast to enclosed dairy barns in Europe and the eastern United States.[10,11] We aimed to determine whether the much larger herd size but open-air ventilation of the facilities in California resulted in lower or higher concentrations of air pollutants relative to previous studies, and whether there were any health concerns due to possibly different types of air pollutants that might be generated on these western US facilities. Given this unique arrangement, we studied whether dairy workers in California have lower baseline and greater cross-shift decrements in lung function than control employees.

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MATERIALS AND METHODS

Study Subjects and Design

Male participants from 13 dairy facilities and a control facility in California completed questionnaires and spirometry before and after the work shifts from June to September 2008. The control facility (a vegetable-processing plant) was selected on the basis of a similar worker population (eg, ethnicity, income, and education) with a night shift. Study design, methods, and survey protocols have been described previously.[12]

Spirometry

All pulmonary function tests (PFTs) were performed by National Institute of Occupational Safety and Health–trained and certified spirometry technicians using EasyOne® spirometers (Medical Technologies, Inc, Andover, MA). Questionable spirograms were reviewed by a pulmonary physician with extensive experience in treating adverse health effects of occupational respiratory exposures.

Two hundred twenty-six dairy workers and 49 control employees completed all study protocols. Of these, 16 dairy workers (7.1%) and two control employees (4.1%) were excluded from PFT analyses because of incomplete or unusable spirograms. The remaining 257 participants were divided into categories on the basis of the variability of the two best maneuvers. The first category followed American Thoracic Society (ATS) recommendations (less than 5% variability).[13] The second, more highly variable (5% to 8% variability category) was created to test whether we could include participants who had less reproducible spirograms, perhaps because they were sick or had less formal education. The spirometry values themselves are less reproducible, but it's also the participants performing spirometry and so in a way they are less reproducible themselves. Sicker patients have a harder time producing reproducible spirograms.[14] Participants with more than 8% variability were excluded from analyses. Each PFT measure was considered separately (ie, a participant could be included in analyses for FEV_1 but if his FVC measures had higher than 8% variability, then he was excluded from FVC analyses). Categorization of ratio measures from participants was based on whichever component in the ratio displayed a greater variability; for example, if a participant had more than 8% variability for FEV_1 but less than 5% variability for FVC, the FEV_1/FVC ratio would be categorized as having more than 8% variability (ie, unusable). To estimate baseline forced expiratory flow between 25% and 75% of FVC ($FEF_{25\%-75\%}$), all the most highly variable spirograms were excluded using the categorization of FEV_1/FVC. Baseline and cross-shift changes in FEV_1, forced expiratory volume in 6 seconds (FEV_6), FVC, $FEF_{25\%-75\%}$, FEV_1/FEV_6, and FEV_1/FVC were modeled separately as outcome measures in regression models. Cross-shift changes were calculated by subtracting the measure before the shift measure from the measure after the shift.

Analysis

To account for possible clustering by facility, we used a mixed-effects multiple linear regression modeling strategy. To facilitate

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comparisons among outcomes, a common set of covariates was specified for baseline and cross-shift. Model selection for each set began with a core set of covariates. For baseline models, the core set included age, height, and smoking status. Smoking status was defined as a dichotomous variable (current vs former/never). A small number of candidate covariates also were evaluated for addition to the core model, including pack-years smoking, years spent in agriculture, years spent in the United States, number of days worked since the last day off, time of the test before the work shift, history of use of personal protective measures, history of time spent working in dust, income, and education level. In cross-shift models, in addition to the core variable of smoking status, the following candidate covariates were considered: whether the participant had smoked any cigarettes that day, time spent in dust that day, time of the work shift, and length of the work shift. Candidate covariates were screened individually with Akaike's information criterion to assess whether the models for most of the outcomes (at either baseline or cross-shift) were improved.[15] Finalization of a parsimonious set of common covariates was achieved by removing those covariates that were highly collinear with other screened-in covariates.

In the cross-shift analyses, we dichotomized the start time of the work shift to adjust for the diurnal variation of lung function.[16,17] For the dichotomous shift-time variable, 12 PM was used as the cutpoint on the basis of the control workers' shift-start times. Because of varying work-shift lengths, we also considered whether the length of the work shift impacted lung function. The dichotomous start-time variable improved the cross-shift models, whereas the length of the work shift was not associated with PFT values and did not improve Akaike's information criterion. Regression models with only the core variable and those including the shift-time variable showed a similar effect; because the shift-time variable improved the model fit (based on Akaike's information criterion), it was included in the final cross-shift models. For cross-shift outcomes, the common set of covariates consisted of the core variable (smoking status) and shift time.

Additional analyses that were restricted to dairy workers explored whether mean levels of select cross-shift outcomes were associated with the presence of self-reported asthma symptoms. Finally, we performed a sensitivity analysis restricted to participants whose spirograms met ATS criteria[13] to determine whether more stringent quality-control criteria would result in substantively different conclusions from analyses including participants with more variable outcomes (less than 8% variability between the two best maneuvers). All statistical analyses were performed using the Statistical Analysis System Software version 9.2 (SAS Institute Inc, Cary, NC).[18]

RESULTS

Demographics

The study population was young, with an average age in the mid-30s for both dairy and control workers. Education levels among both groups were low; fewer than half of the dairy workers attended school past grade 6. Dairy workers earned significantly more than control employees ($P < 0.001$). The vast majority of the participants were Latino, with more than 90% having emigrated from Mexico. Current smoking levels were similar, and the mean of pack-years was low and not significantly different between the two populations (Table 1).

Baseline Pulmonary Function

For baseline outcomes, the covariate for days back at work since the last day off was included with the core baseline covariates (age, height, and smoking status). The final adjusted baseline model approached statistical significance and was suggestive of a chronic association between dairy work and FEV_1 ($P = 0.07$) and FEV_6 ($P = 0.053$) (Table 2). Nevertheless, there was not an association of dairy work and the baseline ratios FEV_1/FEV_6 or FEV_1/FVC ($P = 0.85$ and 0.64, respectively).

TABLE 1. Demographics of Participants With Usable Pulmonary Function Test Results

	Dairy Workers ($n = 210$)		Control Workers ($n = 47$)		
	Mean (SD)	**Median**	**Mean (SD)**	**Median**	***P***
Age, yr	33.6 (11.0)	31.5	35.1 (12.2)	33.0	0.34
Pack-years*	6.2 (10.7)	2.3	6.5 (11.1)	2.5	0.78
	n	**%**	***n***	**%**	
2-week income					<0.001
$0–1000	94	46.8	39	83.0	
>$1000	107	53.2	8	17.0	
Education					0.08
Primary school or less (grade 6 or less)	119	56.7	20	42.6	
More than primary school	91	43.3	27	57.5	
Ethnicity					0.34
Latino	191	94.1	42	97.7	
Non-Latino	12	5.9	1	2.3	
Country of origin					0.02
The United States	4	1.9	3	6.4	
Mexico	189	90.0	44	93.6	
Other	17	8.1	0	0	
Smoking status					0.12
Current smoker	56	26.7	6	12.8	
Former smoker	42	20.0	10	21.3	
Never smoker	112	53.3	31	66.0	

*Pack-years calculated among ever smokers ($n = 106$; 90 dairy workers and 16 control employees).

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Cross-Shift Change in Pulmonary Function

Dairy workers experienced a greater cross-shift decrement than controls in both markers of obstruction (FEV_1) and restriction (FEV_6 and FVC) ($P = 0.02$, 0.002, and 0.002, respectively) after adjusting for smoking status and shift time. The difference between dairy workers and control employees was not statistically significant for FEV_1/FEV_6 or FEV_1/FVC ($P = 0.61$ and 0.42, respectively) (Table 3).

Asthma and Asthma-Like Symptoms

To test whether symptomatic workers were more likely to experience a cross-shift decrement, we modeled the change in FEV_1 and FVC in a regression with the presence of asthma-like symptoms as a dichotomous predictor. Asthma-like symptoms include coughing, wheezing, feeling tightness in the chest, or feeling short of breath when exercising, working, or being exposed to cold air, animals, cows/livestock, dust, pollen, cigarette smoke, grain dust, or dairy chemicals. Only dairy workers were included in these models because complete information about asthma-like symptoms was not collected from among the control employees. Among dairy workers, the presence of asthma-like symptoms was associated with a mean difference in cross-shift FEV_1 of −93.2 mL (95% confidence interval, −130.4 to −35.9 mL; $P < 0.001$) compared with no asthma-like symptoms, after adjusting for smoking status and shift time (Fig. 1). For cross-shift FVC, the presence of asthma-like symptoms was associated with a mean difference of −81.3 mL (95% confidence interval: −140.2 to −22.5 mL; $P = 0.007$) after adjusting for smoking status and shift time (Fig. 1).

Sensitivity Analysis Comparing Results Using ATS Criteria With Main Results

The analyses reported earlier include outcomes from participants with more variable maneuvers than allowed by the strict application of ATS criteria. When the models were restricted to the sample meeting ATS criteria, the estimates varied slightly from the main analyses for all measures, but the direction and statistical significance were identical between the group with only the “best” spirograms and the group with both the “best” spirograms and the more variable participants (results not shown).

DISCUSSION

Acute Change in Pulmonary Function

The cross-shift decline in FEV_1 ($P = 0.02$) suggests an association of exposure with airway obstruction among dairy workers. In addition, with a significant cross-shift decline in FEV_6 ($P = 0.002$)

TABLE 2. Dairy Versus Control: Baseline Adjusted Least Square Means and Estimated Contrasts in Mean Pulmonary Function Measures

		Mean Pulmonary Function*			Adjusted Mean Dairy vs Control Difference From Full Model†	
	N	Dairy (*n* = 210), Estimate (95% CI)	Control (*n* = 47), Estimate (95% CI)	*P*	Estimate (95% CI)	*P*
FEV_1, L	253	3.62 (3.56–3.68)	3.73 (3.60–3.86)	0.14	− 0.13 (−0.28 to 0.01)	0.07
FEV_6, L	251	4.42 (4.35–4.49)	4.57 (4.42–4.71)	0.08	− 0.16 (−0.33 to 0.00)	0.053
FVC, L	253	4.54 (4.47–4.61)	4.65 (4.50–4.80)	0.18	− 0.13 (−0.30 to 0.04)	0.13
$FEF_{25\%–75\%}$, L/s	250	3.78 (3.64–3.93)	3.81 (3.50–4.12)	0.86	− 0.06 (−0.41 to 0.29)	0.73
FEV_1/FEV_6, %	248	81.9 (81.2–82.6)	81.8 (80.4–83.2)	0.87	− 0.28 (−4.3 to 3.7)	0.85
FEV_1/FVC, %	250	80.0 (79.2–80.8)	80.3 (78.6–82.0)	0.66	− 1.03 (−6.7 to 4.7)	0.64

CI, confidence interval; FEF, forced expiratory flow; FEV_1: forced expiratory volume in 1 second; FEV_6, forced expiratory volume in 6 seconds; FVC, forced vital capacity.

* Least square means adjusted for age and height squared.

†Effect of dairy was calculated by estimating the contrast between dairy and control workers in a mixed-effects model after statistically adjusting for age, height squared, smoking status, and days back at work since last day off.

TABLE 3. Dairy Versus Control: Cross–Work-Shift Adjusted Least Square Mean Changes and Estimated Contrasts in Mean Pulmonary Function Measures

		Mean Cross-Shift Change in PFT*, Estimate (95% CI)		Dairy Regression Coefficient in Full Model†	
	N	Dairy Workers (*n* = 210)	Control Workers (*n* = 47)	Estimate (95% CI)	*P*
ΔFEV_1, mL	253	− 48.3 (−73.6 to −23.0)	15.9 (−34.9 to 66.7)	− 65.2 (−118.6 to −11.9)	0.02
ΔFEV_6, mL	251	− 56.5 (−85.2 to −27.8)	33.8 (−23.5 to 91.0)	− 96.0 (−155.2 to −36.8)	0.002
ΔFVC, mL	253	− 41.9 (−72.8 to −10.9)	56.3 (−6.1 to 118.7)	− 103.1 (−168.2 to −38.0)	0.002
$\Delta FEF_{25\%–75\%}$, mL/s	250	− 73.7 (−148.9 to 1.5)	− 14.3 (−163.8 to 135.1)	− 53.6 (−210.5 to 103.2)	0.50
$\Delta FEV_1/FEV_6$, %	248	− 0.24 (−0.56 to 0.09)	− 0.34 (−0.98 to 0.30)	0.17 (−0.49 to 0.83)	0.61
$\Delta FEV_1/FVC$, %	250	− 0.49 (−0.85 to −0.13)	− 0.75 (−1.47 to −0.03)	0.31 (−0.45 to 1.06)	0.42

CI, confidence interval; FEF, forced expiratory flow; FEV_1, forced expiratory volume in 1 second; FEV_6, forced expiratory volume in 6 seconds; FVC, forced vital capacity; PFT, pulmonary function test.

*Least square means adjusted for smoking status.

†The cross-shift effect of dairy was calculated by estimating the contrast between dairy and control workers in mixed-effect models after statistically adjusting for smoking status and the time of work shift.

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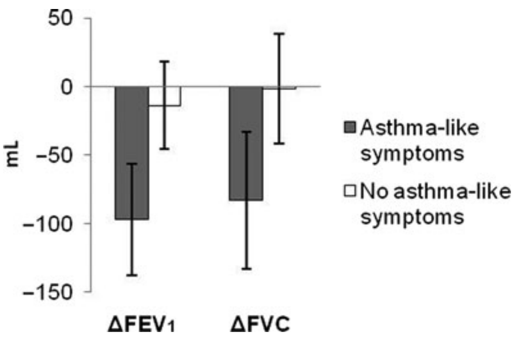

FIGURE 1. Association of cross-shift changes in forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC) and asthma-like symptoms among dairy workers. Least square means and 95% confidence intervals are represented among dairy workers. Asthma-like symptoms were defined as self-reported coughing, wheezing, feeling tightness in the chest, or feeling short of breath when exercising, working, or when exposed to cold air, animals, cows/livestock, dust, pollen, cigarette smoke, grain dust, or dairy chemicals. Sample size for each category: asthma-like symptoms: $n = 79$; no asthma-like symptoms: $n = 129$.

and FVC ($P = 0.002$), there seems to be a mild acute restrictive function change among dairy workers. Both percent predicted FEV_1 and percent predicted FVC are key indicators of occupational asthma.[19] Additional markers of airway obstruction (ie, the ratios of FEV_1/FVC and FEV_1/FEV_6) were not significantly associated with dairy work, indicating that FEV_1 did not show a greater cross-shift decrease than FVC (or FEV_6) and pointing to a mixed airways effect.

Industrial bronchitis (also known as acute reversible airway inflammation) has been defined as cough, phlegm production, and mild airflow obstruction associated with occupational exposure to dust or fumes.[20] About 20% of dairy (45 of 210; 21.3%) and control (9 of 49; 19.2%) workers experienced either cough or phlegm production during their work shifts. In contrast, few dairy (7 of 210; 3.3%) and control (1 of 49; 2.1%) participants experienced both cough and phlegm during their work shifts. Forced vital capacity can be reduced in industrial bronchitis,[20] in keeping with our findings of reduced FVC and FEV_1. Furthermore, industrial bronchitis primarily affects the large airways, leading to reversible obstruction.[20] Although industrial bronchitis does not exactly describe our findings, the inconclusive findings of baseline FEV_1 and FVC with respect to dairy work as well as mild mixed effects of acute restriction and acute obstruction point to a condition similar to industrial bronchitis and merit further investigation. Specifically, it would be useful to measure inflammatory toxicity of dairy dust, as we have done for other agricultural dusts,[21] and to study acute markers of inflammation among workers.

Asthma-Like Symptoms

Given that one fifth of the workers in this study had never accessed medical care in the United States,[12] we used a more sensitive indicator of asthma, "asthma-like symptoms," instead of doctor-diagnosed asthma. Dairy workers with asthma-like symptoms had significantly greater cross-shift decrements in FEV_1 than dairy workers without asthma-like symptoms, indicating that they are a susceptible population. Because they represent about 40% (80 of 210) of the dairy participants, intervention efforts should target this susceptible population. Nevertheless, asthma-like symptoms include several nonspecific symptoms (including shortness of breath and coughing) that could be due to multiple causes.[22] Unfortunately, we cannot assess causality of asthma-like symptoms and pulmonary function in a cross-sectional study. Either way, dairy workers experiencing asthma-like symptoms merit particular attention in further investigations to disentangle the lung function and symptoms.

Association of Acute and Chronic Pulmonary Function in Dairy Workers

Because baseline values of FEV_1 and FEV_6 are marginally associated with dairy work ($P = 0.07$ and 0.053, respectively), the association of dairy work and chronic measures of pulmonary function remains unclear. Longitudinal studies in France have shown mixed long-term effects of dairy work; it is associated with a moderate decrease in FEV_1 that is heightened with more time spent on dairies and among older male subjects.[3,5] Studies among swine farmers, coal miners, and cotton textile workers have shown that an acute change in pulmonary function leads to a long-term decrement.[23–25] A 3% decrement in cross-shift lung function has been used previously as epidemiologically relevant to predict long-term effects and recommend exposure limits.[9,26] Although the unadjusted mean levels of cross-shift change in FEV_1, FEV_6, and FVC among dairy workers in this study were −1.3%, −1.3%, and −0.9%, respectively, almost one third (62 of 210; 30%) of dairy workers experienced a 3% or more decrement in FEV_1, indicating that they are at risk of developing a chronic deficit in FEV_1 compared with 15% (7 of 49) of control employees (Fig. 2). Almost one third (61 of 210; 29%) of dairy workers and 13% (6 of 49) of control employees experienced a decrement of 3% or more in FVC (Fig. 3).

Studies among swine farmers indicate that long-term effects become apparent after 6 to 10 years of exposure.[8,9,27] Because half of the dairy workers in this study have spent 5 years or fewer on dairies, they might not have been exposed long enough to show chronic conditions. Nevertheless, a study of Danish swine farmers showed an accelerated decline in FEV_1 compared with dairy farmers; the

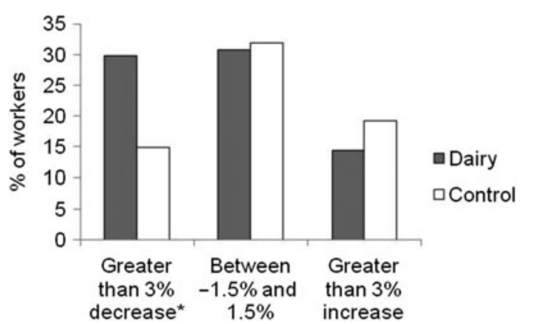

FIGURE 2. Categorization of cross-shift percent change in forced expiratory volume in 1 second by employment status (dairy or control). *$P < 0.05$.

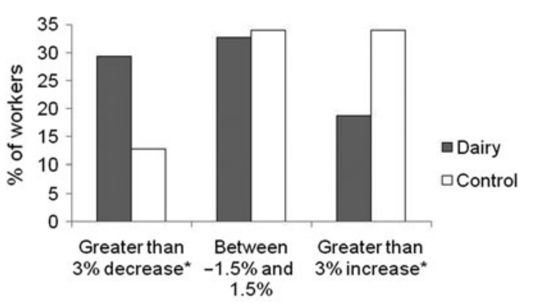

FIGURE 3. Categorization of cross-shift percent change in forced vital capacity by employment status (dairy or control). *$P < 0.05$.

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dairy farmers' decline in FEV_1 was close to the expected values,[28] suggesting that there might not be a long-term effect of dairy work on FEV_1. In contrast, a longitudinal French study found an association between dairy farming and moderate bronchial airway obstruction.[1] We were unable to include both years working on a dairy and age in the same model because they are collinear, making it difficult to draw conclusions concerning the long-term effect of dairy work. Taking a subsample of only nonsmoking participants older than the median age (32 years) to assess long-term respiratory effects yielded results similar to those of the whole population (results not shown). Dairy workers in California likely do not show clear chronic respiratory effects because the population is too young to display a cumulative impact of working on dairies. In addition, previous studies have been conducted in Europe, where animals are confined in an enclosed building, unlike in California, where there are open, outdoor facilities, which results in lower exposures.[29]

Light Smoking

The young Latino study subjects were light and infrequent smokers, consistent with published reports.[30,31] Among current smokers, the median number of cigarettes per day was three and one among dairy and control workers, respectively. We explored several options of smoking variables to be included in the final models, including a five-level variable that was a combination of smoking status and pack-years. The final models use a dichotomous smoking variable (current vs former/never) because none of the explored options provided additional explanatory power. None of the smoking variables explored (including the final dichotomous variable) were significant in either the baseline or cross-shift models. It is likely that this young population simply has not smoked enough cigarettes long enough to show a significant respiratory effect.

LIMITATIONS

Differences between dairy workers and control employees in income and smoking prevalence could introduce bias when making comparisons. Nevertheless, the difference would likely not be sufficient to create a meaningful difference in socioeconomic levels that might affect health practices, particularly because ethnicity and education levels were similar between dairy and control workers. In addition, smoking was not a significant predictor of lung function independent of employment as discussed previously.

Selection bias might be introduced by the healthy worker effect. Individuals who are unduly affected by dairy work could self-select out of the profession and thus would not be included in our sample, biasing our estimates toward the null. Nevertheless, because the dairy and control workers are similar in age and ethnicity, it is less likely that the healthy worker effect affects our results.

Additional studies of pulmonary function are necessary to identify the long-term respiratory health consequences of working in large dairies in California. Asthma and asthma-like symptoms merit further attention because almost half of the dairy workers (40%) in this study reported experiencing asthma-like symptoms. In this population with low education and limited access to health care, doctor-diagnosed asthma has questionable value. For this reason, we used "asthma-like symptoms" to encompass a broad range of nonspecific symptoms that could result from various exposures. A larger sample size would allow researchers to more completely characterize work tasks around a Californian dairy. Furthermore, a longitudinal study would provide the information needed to determine temporality of respiratory symptoms, including asthma.

CONCLUSIONS

Dairy work was associated with a mixed airways effect across the work shift, with reduction in measures of both airflow and the vital capacity of the lung. Because baseline values were marginally significant, the effect seems to be reversible in this population. Nevertheless, because acute changes in pulmonary function may predict long-term effects, the chronic effects of dairy work in California remain unclear. Given their nonmigratory nature, a longitudinal study of dairy workers in California is feasible and would elucidate the chronic effects of dairy work on lung health.

Asthma and asthma-like symptoms should be further researched among dairy workers in California because a large proportion of our dairy participants (40%) reported asthma-like symptoms. Future investigations should expand and separate asthma-like symptoms because the current definition includes several nonspecific symptoms.

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