Dust Exposure and Coccidioidomycosis Prevention Among Solar Power Farm Construction Workers in California

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Objectives. To investigate if work activities, dust exposure, and protection measures were associated with a 2011 to 2014 coccidioidomycosis outbreak among workers constructing 2 solar farms in California.

Methods. In 2013, we mailed self-administered questionnaires to employees who were onsite at the solar farms where the outbreak occurred to identify cases of clinical coccidioidomycosis and compare with asymptomatic workers by using multivariate logistic regression.

Results. When we compared 89 workers with clinical coccidioidomycosis to 325 asymptomatic workers, frequently being in a dust cloud or storm (odds ratio [OR] = 5.93; 95% confidence interval [CI] = 3.18, 11.06) significantly increased the odds of clinical coccidioidomycosis, whereas frequently wetting soil before soil-disturbing activity (OR = 0.42; 95% CI = 0.24, 0.75) was protective. When we controlled for being in a dust cloud or storm, frequent soil disturbance significantly increased the odds of clinical coccidioidomycosis only among those who reported wearing a respirator infrequently (OR = 2.31; 95% CI = 1.27, 4.21).

Conclusions. Utilization of personal and employer-driven safety practices and increased coccidioidomycosis awareness among construction workers should be considered during the planning of any construction work in coccidioidomycosis-endemic regions to prevent occupational infections and outbreaks. (*Am J Public Health.* 2017;107:1296–1303. doi:10.2105/AJPH.2017.303820)

Coccidioidomycosis (valley fever) is an infectious disease caused by the soil-dwelling *Coccidioides* fungus.[1–4] It is endemic in the southwestern United States with the highest rates reported from Arizona and California.[2,3,5–7] Infected persons are asymptomatic or develop disease ranging from influenza-like illness or pneumonia to severe and potentially fatal disseminated disease.[8,9] Common symptoms are often nonspecific, including fatigue, cough, fever, night sweats, chest pain, arthralgia, myalgia, and rash, and illness often lasts a few weeks or more.[2,10]

Most infections occur when soil containing fungal arthrospores is disturbed by wind or human activities leading to their inhalation.[2] As a consequence, occupational soil-disturbing activities such as construction work in endemic areas can increase risk for coccidioidomycosis; however, studies identifying specific work-related risk factors are limited.[11,12] Current guidance for employers performing dirt disturbance in endemic areas includes dust suppression and worker education, but no studies have identified prevention measures.

During 2011 to 2014, an outbreak of coccidioidomycosis occurred among workers constructing 2 neighboring solar power-generating facilities (solar farms) in San Luis Obispo County, California.[13] A total of 44 cases among 3572 workers were laboratory-confirmed to have a *Coccidioides* infection. An incidence rate of 5618 cases per 100 000 person-years was calculated as compared with the 2012 incidence rate for San Luis Obispo County of 38.4 cases per 100 000 population. Of the confirmed patients, 9 of 44 were hospitalized, 34 of 41 missed work, and 2 of 44 were diagnosed with disseminated disease. Recommendations were made for improving dust-control measures onsite and ensuring prompt reporting of additional cases.

With evidence of coccidioidomycosis occurring among workers constructing solar farms and plans for construction of additional solar farms throughout the endemic regions of California, further evaluation of construction-related risk of coccidioidomycosis is necessary to better protect workers.[14] We conducted an epidemiological investigation of workers at the outbreak-related solar farms to identify cases of clinical coccidioidomycosis and compare with asymptomatic workers to assess any associations with work activities, dust exposure, or prevention measures.

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METHODS

In our previous report on the San Luis Obispo County coccidioidomycosis outbreak, we defined a confirmed case as clinical- and laboratory-confirmed coccidioidomycosis in an employee of either solar farm A or B, with illness onset 1 week or longer after beginning work but not more than 1 month after the last workday at either solar farm.[13] Case-patients were interviewed via a standardized phone survey instrument to collect demographic, clinical, work activity, and safety practice data.[13]

To obtain data on other workers at the solar farms, we developed a self-administered questionnaire with questions on employment, previous coccidioidomycosis diagnosis, illness occurring since beginning work at the solar farm, work activities, safety practices, and demographics; we designed the questionnaire to be comparable with the confirmed case-patient phone interview. We obtained employee rosters from identified employers at the solar farms and, in December 2013, mailed 3707 questionnaires to 3572 individual workers listed on all available rosters; some workers listed multiple addresses. We sent questionnaires to 925 workers from solar farm A, 2457 from solar farm B, and 190 who had worked at both solar farms. Questionnaires were not sent to the 44 previously identified coccidioidomycosis patients.

Questionnaire Respondent Classification

We classified questionnaire respondents into 1 of 3 categories (worker with a syndromic clinical case of coccidioidomycosis, asymptomatic worker, and symptomatic noncase) on the basis of their responses to questions on illness occurring since beginning work at the solar farm. Workers were asked,

> Since beginning work at [solar farm A or B], have you felt sick for 4 weeks or longer with some of the following symptoms: difficulty breathing, chest pain, cough, fever, night sweats, weight loss, fatigue/tiredness, weakness, muscle or joint pain, rash or skin lesions, headache?

If "Yes," workers were asked for an approximate illness onset date and to specify which of the previously listed symptoms they experienced.

We defined a clinical case as reporting feeling sick for 4 weeks or longer, reporting an illness onset date 1 week or more after beginning work but not more than 1 month after the last workday at either solar farm, and reporting at least 1 respiratory symptom (difficulty breathing or cough) and at least 2 of the following symptoms: fever, fatigue, chest pain, or night sweats. Clinical cases were not laboratory-confirmed. We intended the specified case definition to identify clinical illnesses that were more likely to be coccidioidomycosis than illnesses attributable to other common infections (e.g., influenza or viral or bacterial pneumonia).

We classified respondents who reported feeling sick but who did not meet all clinical case definition criteria as symptomatic noncases. We classified respondents who reported no symptoms and no illness as asymptomatic workers. If an asymptomatic worker was employed at both solar farms and returned a separate questionnaire for each, we included only data from the site of most recent employment. We excluded respondents who reported having a coccidioidomycosis diagnosis before employment at the solar farm.

Descriptive Data and Classification

Demographic, employment, and work activity data were asked of questionnaire respondents. We dichotomized residence data by state of permanent residence; we defined California, Arizona, Nevada, New Mexico, Texas, and Utah as endemic states, and we classified all other states as nonendemic. Occupation and primary job duty were reported in a free text field and classified into major job categories. We classified respondents reporting being current or former smokers as smokers.

Several questions related to the frequency of work activities and safety practices onsite were measured with a Likert scale. We collapsed responses to questions regarding frequency of performing specific work activities, being moved or sent home because of high dust, or being in a dust storm or cloud to "frequently" ("every day" or "once a week") and "infrequently" ("rarely" or "never"). Workers who reported performing active digging, working in a ditch or trench, or operating heavy machinery "frequently" were classified as having performed soil-disturbing activities "frequently" whereas all others were classified as "infrequently." If workers reported that they "frequently" operated heavy machinery, yet the cab was enclosed and windows were kept closed, frequency of heavy machinery operation was reclassified as "infrequently" because the dust exposure risk of the activity was presumably mitigated. We collapsed responses to questions regarding how often personal safety practices were performed (i.e., showering immediately at home after work, washing up before lunch, washing up at the end of the day before leaving work, wearing a respirator while working, and changing out of work clothes before leaving work) and how often soil was wetted before being disturbed by digging, grading, or other activities to "frequently" ("always" or "often") and "infrequently" ("sometimes," "rarely," or "never").

We summarized clinical data including symptoms and reports of missed work for confirmed case-patients, workers with clinical coccidioidomycosis, and symptomatic noncases. In addition, we analyzed and reported demographic, employment, work activity, and safety practice data by asymptomatic worker and clinical case status. Denominator data for all reported percentages varied on the basis of the number of workers who answered each question.

Statistical Analyses

To assess potential associations between demographic, employment, work activity, and safety practice factors and clinical coccidioidomycosis, we used logistic regression to compare clinical cases and asymptomatic workers. We calculated bivariate odds ratios (ORs), 95% confidence intervals (CIs), and *P* values for each factor. We calculated multivariate results for key factors (performing soil-disturbing activities, wearing a respirator, being in a dust cloud or storm, and soil being wetted before soil disturbance). We also separately investigated potential confounding and effect modification for the effects of wearing a respirator and of wetting the soil on a model including performing soil-disturbing activities and being in a dust cloud or storm.

We performed 2 sensitivity analyses and, for both, we recalculated bivariate and

TABLE 1—Characteristics of Questionnaire Respondents Among Solar Farm Construction Workers: San Luis Obispo County, CA, 2011–2014

Characteristics	No./Total No. (%[a]) or Mean, Median (Range)
Employment at solar farm B	347/556 (62.4)
Male	474/538 (88.1)
Age, y	44, 45 (18–83)
Non-Hispanic White race/ethnicity	399/521 (76.6)
Hispanic race/ethnicity	88/521 (16.9)
Endemicity of state residence[b]	467/540 (86.5)
Smoker	221/542 (40.8)
Reported a chronic medical condition	78/556 (14.0)
Hours worked outdoors/week	43, 43 (0.2–84)
Job category	
Electrician	189/553 (34.2)
Operating engineer or driver	85/553 (15.4)
General construction or labor	70/553 (12.7)
Archeology, biology, or conservation	60/553 (10.8)
Oversight or supervision	41/553 (7.4)
Metal or wood working	33/553 (6.0)
Other[c]	75/553 (13.6)
Frequently performed the following job activities[d]	
Soil-disturbing activities	249/543 (45.9)
Active digging	109/517 (21.1)
Working in ditch or trench	165/524 (31.5)
Operating heavy machinery[e]	100/531 (18.8)
Frequently in dust cloud or storm[d]	259/541 (47.9)
Respirator fit tested	255/509 (50.1)
Frequently performed the following personal safety practices[f]	
Showered immediately at home after work	366/550 (66.5)
Washed up before lunch	244/547 (44.6)
Washed up at end of the day before leaving work	156/547 (28.5)
Wore respirator	68/543 (12.5)
Changed out of work clothes before leaving work	25/546 (4.6)
Frequently moved or sent home because of high dust[d]	13/546 (2.4)
Reported soil was wetted frequently before soil-disturbing activity[f]	240/512 (46.9)

Note. Total number excludes 2 with previous coccidioidomycosis diagnosis. The sample size was n = 556.

[a]Percentage denominators vary by the number of workers responding to each question as indicated.

[b]We defined endemic states as Arizona, California, Nevada, New Mexico, Texas, and Utah. We defined all other states as nonendemic.

[c]Compliance/safety, engineer/architect, machinery work, nonconstruction/office work, other skilled technician.

[d]Frequently (every day or once a week), infrequently (rarely or never).

[e]Workers who operated heavy machinery with a closed cab and closed windows were classified as having operated heavy machinery infrequently.

[f]Frequently (always or often), infrequently (sometimes, rarely, or never).

multivariate results. For the first sensitivity analysis, we investigated whether we would see similar results as the clinical coccidioidomycosis analysis when we compared the previously identified confirmed cases to the asymptomatic workers. In the second sensitivity analysis, we compared workers with clinical coccidioidomycosis to a combined group of asymptomatic workers and the symptomatic noncases.

We defined statistical significance as a P value less than or equal to .05. We performed all analyses in SAS 9.4 (SAS Institute Inc, Cary, NC).

RESULTS

We received completed questionnaires from 558 individual respondents, 15.6% of the 3572 individual workers returned questionnaires. A total of 190 of 925 (20.5%) workers from solar farm A responded, 335 of 2457 (13.6%) from solar farm B, and 33 of 190 (17.4%) who worked at both solar farms. We excluded 2 respondents who had coccidioidomycosis diagnosis before solar farm employment. Of the other 556 questionnaire respondents, 89 (16.0%) were classified as clinical cases of coccidioidomycosis, 325 (58.4%) as asymptomatic workers, 137 (24.6%) as symptomatic noncases, and the remaining 5 (0.9%) did not provide data on illness or symptoms. In addition, phone interview data from the initial outbreak investigation were available on work practices and symptoms for 43 and 41 of the 44 laboratory confirmed case-patients, respectively.

Descriptive Statistics

Of the 556 questionnaire respondents, most were male, non-Hispanic White, and residents of endemic states (Table 1). The median age was 45 years. Approximately 40% reported being current or former smokers. None reported having immunocompromising conditions. On average, respondents reported working 43 hours per week outdoors, and the most common job category was electrician (189 of 553; 34.2%). Of the 126 workers who reported frequently operating heavy machinery, 26 (20.6%) reported having an enclosed cab and keeping windows closed; these workers were reclassified as having operated heavy machinery infrequently. Approximately half of the respondents reported frequently performing soil-disturbing activities (249 of 543; 45.9%), frequently being in a dust cloud or storm (259 of 541; 47.9%), and that soil was frequently wetted before soil-disturbing

activity (240 of 512; 46.9%). Although 50.1% (255 of 509) of respondents reported being fitted for respirator use, only 12.5% (68 of 543) reported frequently wearing a respirator.

Of the 41 confirmed case-patients who reported symptom data, 38 (92.7%) met the clinical case definition, and the other 3 (7.3%) did not report cough or difficulty breathing (Table 2). More than 80% of workers with confirmed or clinical coccidioidomycosis reported cough, difficulty breathing, fatigue, night sweats, fever, muscle or joint pain, weakness, and headache. Weight loss was reported by nearly 85% of confirmed case-patients (mean 22 pounds) and 45% of workers with clinical coccidioidomycosis (mean 20 pounds). Missed work because of illness was reported by 87.8% of confirmed case-patients and 46.3% of those with clinical coccidioidomycosis.

Although the 137 symptomatic noncases did not meet our clinical case definition criteria, symptoms suggestive of coccidioidomycosis were reported with high frequency (Table 2). However, 29 (21.2%) reported illness onset too soon after starting work or too long after their last day of work for their illness to be considered as coccidioidomycosis associated with being at the solar farm, and 67 (48.9%) were missing onset date or first or last work date. The remaining 41 workers and some of the 67 workers with missing dates did not meet our symptom criteria but could have had coccidioidomycosis associated with their work at the solar farm.

Risk of Clinical Coccidioidomycosis

We found no significant differences in demographic characteristics, residence in endemic versus nonendemic state, or chronic medical conditions of the 89 workers with clinical coccidioidomycosis compared with asymptomatic workers in the bivariate regression (Table 3). Current or former smokers had 1.67 times the odds of having clinical coccidioidomycosis (95% CI = 1.04, 2.69) than did nonsmokers. Those who worked outdoors more than 40 hours per week were more likely to be a worker with clinical coccidioidomycosis than did those who worked 40 hours or less (OR = 2.03; 95% CI = 1.26, 3.25).

Workers who reported frequently performing soil-disturbing activities also had greater odds of clinical coccidioidomycosis (OR = 2.99; 95% CI = 1.83, 4.88). Frequently performing active digging (OR = 1.87; 95% CI = 1.07, 3.27), working in a ditch or trench (OR = 2.91; 95% CI = 1.77, 4.78), and operating heavy machinery without an enclosed cab with closed windows

TABLE 2—Clinical Characteristics of Workers With Confirmed and Clinical Coccidioidomycosis and Symptomatic Noncases Among Solar Farm Construction Workers: San Luis Obispo County, CA, 2011–2014

Characteristics	Confirmed Coccidioidomycosis (n = 41[a]), No./Total No. (%[b]) or Mean, Median (Range)	Clinical Coccidioidomycosis (n = 89),[c] No./Total No. (%[b]) or Mean, Median (Range)	Symptomatic Noncases (n = 137),[c] No./Total No. (%[b]) or Mean, Median (Range)
Clinical case symptoms criterion[d]	38/41 (92.7)	89/89 (100.0)	50/137 (36.5)
Clinical case, respiratory symptoms	38/41 (92.7)	89/89 (100.0)	100/137 (73.0)
Cough	33/39 (84.6)	88/89 (98.9)	89/109 (81.7)
Difficulty breathing	37/39 (94.9)	71/82 (86.6)	62/92 (67.4)
Clinical case, other symptoms	41/41 (100.0)	89/89 (100.0)	66/137 (48.2)
Fatigue	40/40 (100.0)	85/85 (100.0)	108/123 (87.8)
Night sweats	39/40 (97.5)	69/77 (89.6)	56/89 (62.9)
Fever	35/37 (94.6)	61/75 (81.3)	33/78 (42.3)
Chest pain	29/40 (72.5)	60/80 (75.0)	35/77 (45.5)
Other symptoms			
Muscle or joint pain	33/38 (86.8)	76/80 (95.0)	89/108 (82.4)
Weakness	38/40 (95.0)	74/82 (90.2)	82/105 (78.1)
Headache	27/31 (87.1)	66/78 (84.6)	78/101 (77.2)
Weight loss	33/39 (84.6)	28/63 (44.4)	36/86 (41.9)
Pounds lost	22, 20 (3–100)	20, 15 (4–45)	17, 15 (4–40)
Rash or skin lesions	24/37 (64.9)	27/67 (40.3)	30/79 (38.0)
Missed work	36/41 (87.8)	37/80 (46.3)	32/113 (28.3)
Days of missed work	98, 22 (1–547)	9, 5 (2–60)	9, 5 (1–90)

[a]Of 43 confirmed patients with interview data, 41 provided data on symptoms and missed work.

[b]Percentage denominators vary by the number of workers responding to each question as indicated.

[c]Questionnaire respondents (excludes confirmed case-patients) reported specific symptoms in response to the following question: "Since beginning work at [solar farm A/B], have you felt sick for 4 weeks or longer with some of the following symptoms: difficulty breathing, chest pain, cough, fever, night sweats, weight loss, fatigue/tiredness, weakness, muscle or joint pain, rash or skin lesions, headache? If Yes, specify below which symptoms you experienced at all during that time period." Symptomatic noncases may have specified symptoms yet replied "No" or "Don't know" to the initial "sick for 4 weeks" question.

[d]Clinical case symptom criterion required report of feeling sick for 4 weeks or longer with at least 1 respiratory symptom (cough or difficulty breathing) and at least 2 of the following symptoms: fatigue, night sweats, fever, or chest pain. Confirmed cases were not required to meet the clinical case symptom criterion.

TABLE 3—Comparison of Workers With Clinical Coccidioidomycosis to Asymptomatic Workers Among Solar Farm Construction Workers: San Luis Obispo County, CA, 2011–2014

Characteristics	Asymptomatic Workers (n = 325), No. (%[a])	Clinical Coccidioidomycosis (n = 89), No. (%[a])	OR (95% CI)
Gender (n = 401)			
Female	43 (13.7)	10 (11.4)	1 (Ref)
Male	270 (86.3)	78 (88.6)	1.24 (0.60, 2.59)
Age group, y (n = 379)			
18–34	91 (31.1)	27 (31.4)	1 (Ref)
35–54	117 (39.9)	43 (50.0)	1.24 (0.71, 2.16)
≥ 55	85 (29.0)	16 (18.6)	0.63 (0.32, 1.26)
Race/ethnicity (n = 381)			
White	241 (80.6)	61 (74.4)	1 (Ref)
Hispanic	42 (14.0)	13 (15.9)	1.22 (0.62, 2.42)
Other[b]	16 (5.4)	8 (9.8)	1.98 (0.81, 4.83)
Endemicity of state residence (n = 401)[c]			
Endemic	273 (87.2)	79 (89.8)	1 (Ref)
Nonendemic	40 (12.8)	9 (10.2)	0.78 (0.36, 1.67)
Smoker (n = 401)			
No	199 (63.6)	45 (51.1)	1 (Ref)
Yes	114 (36.4)	43 (48.9)	1.67 (1.04, 2.69)
Any chronic medical conditions (n = 414)			
Not indicated	287 (88.3)	73 (82.0)	1 (Ref)
Yes	38 (11.7)	16 (18.0)	1.66 (0.88, 3.13)
Solar farm (n = 414)			
B	215 (66.2)	58 (65.2)	1 (Ref)
A	110 (33.8)	31 (34.8)	1.05 (0.64, 1.71)
Time working outdoors/week (n = 414)			
≤ 40 h	199 (61.2)	39 (43.8)	1 (Ref)
> 40 h	126 (38.8)	50 (56.2)	2.03 (1.26, 3.25)
Frequently performed the following job activities[d,e]			
Soil-disturbing activities (n = 405)	118 (37.3)	57 (64.0)	2.99 (1.83, 4.88)
Active digging (n = 390)	53 (17.4)	24 (28.2)	1.87 (1.07, 3.27)
Working in ditch or trench (n = 394)	72 (23.5)	41 (47.1)	2.91 (1.77, 4.78)
Operating heavy machinery[f] (n = 397)	44 (14.2)	28 (32.2)	2.87 (1.65, 4.98)
Frequently in a dust cloud/storm (n = 401)[d,e]	95 (30.2)	69 (80.2)	9.40 (5.25, 16.83)
Respirator fit tested (n = 378)			
No	157 (53.0)	39 (47.6)	1 (Ref)
Yes	139 (47.0)	43 (52.4)	1.25 (0.76, 2.03)

Continued

(OR = 2.87; 95% CI = 1.65, 4.98) were each associated with clinical coccidioidomycosis. Those who reported frequently being in a dust cloud or storm compared with those who reported it infrequently had 9.40 times the odds of clinical coccidioidomycosis (95% CI = 5.25, 16.83). Neither being fitted for a respirator nor frequently wearing a respirator was protective against clinical coccidioidomycosis. However, frequently washing up before lunch (OR = 0.50; 95% CI = 0.31, 0.82), frequently washing up at the end of the day (OR = 0.57; 95% CI = 0.33, 0.98), and soil being frequently wetted before disturbance (OR = 0.28; 95% CI = 0.17, 0.46) were protective.

In the multivariate analysis, frequently being in a dust cloud or storm was positively associated (OR = 5.93; 95% CI = 3.18, 11.06) and frequently wetting the soil before disturbance was negatively associated (OR = 0.42; 95% CI = 0.24, 0.75) with clinical coccidioidomycosis (Table 4). When we stratified a model including only soil-disturbing activities and being in a dust cloud or storm by respirator use, frequently being in a dust cloud or storm remained significant

TABLE 3—*Continued*

Characteristics	Asymptomatic Workers (n = 325), No. (%[a])	Clinical Coccidioidomycosis (n = 89), No. (%[a])	OR (95% CI)
Frequently performed the following personal safety practices[g,h]			
Showered immediately at home after work (n = 408)	208 (65.2)	61 (68.5)	1.16 (0.70, 1.92)
Washed up before lunch (n = 405)	169 (53.3)	32 (36.4)	0.50 (0.31, 0.82)
Washed up at the end of the day before leaving work (n = 406)	113 (35.5)	21 (23.9)	0.57 (0.33, 0.98)
Wore a respirator (n = 402)	36 (11.4)	12 (13.8)	1.24 (0.62, 2.50)
Soil wetted frequently before soil-disturbing activity (n = 373)[d,g]	179 (62.8)	28 (31.8)	0.28 (0.17, 0.46)

Note. CI = confidence interval; OR = odds ratio. Comparisons made by using bivariate logistic regression.
[a]Percentage denominators vary by the number of workers responding to each question as indicated.
[b]African American, Asian/Pacific Islander, American Indian, other.
[c]Endemic states defined as Arizona, California, Nevada, New Mexico, Texas, and Utah. All other states defined as nonendemic.
[d]Logistic regression reference group was "infrequently".
[e]Frequently (every day or once a week), infrequently (rarely or never).
[f]Workers who operated heavy machinery with a closed cab or closed windows were classified as having operated infrequently.
[g]Frequently (always or often), infrequently (sometimes, rarely, never).
[h]Excluded "Changed out of work clothes before leaving work" and "Moved or sent home due to high dust" because of small numbers.

regardless of respirator use (frequent respirator use: OR = 7.02; 95% CI = 1.17, 42.30; infrequent respirator use: OR = 8.26; 95% CI = 4.27, 15.96) yet performing soil-disturbing activities was only significant among those who infrequently wore respirators (OR = 2.31; 95% CI = 1.27, 4.21). We found no confounding or effect modification when we stratified the model (excluding respirator use) by wetting soil before disturbance.

In our 2 sensitivity bivariate analyses (1) comparing only confirmed case-patients to asymptomatic workers and (2) comparing those with clinical coccidioidomycosis to asymptomatic workers combined with symptomatic noncases, most factors from the clinical case analysis retained their state of significance with similar OR magnitudes, including frequently performing dirt-disturbing work and frequently being in a dust cloud or storm (data not shown). In both sensitivity analyses, frequently washing up before lunch and at the end of work shift and frequently performing active digging were no longer significant.

In the confirmed case analysis, employment at solar farm A was significantly associated with infection ($P < .01$) but frequently operating heavy machinery was no longer significant. In the analysis comparing clinical cases to asymptomatic workers and symptomatic noncases, smoking and time working outdoors per week were no longer significant. Several factors in the confirmed case analysis could not be assessed because of small numbers, including gender, race/ethnicity, state endemicity, and chronic medical conditions. In both sensitivity multivariate analyses, the only factor that was significantly associated with clinical coccidioidomycosis was frequently being in a dust

TABLE 4—Multivariate Logistic Regression Results Comparing Solar Farm Construction Workers With Clinical Coccidioidomycosis to Asymptomatic Workers and Results for Supporting Sensitivity Analyses: San Luis Obispo County, CA, 2011–2014

Factors	Clinical Coccidioidomycosis vs Asymptomatic Workers, OR (95% CI)	Confirmed Coccidioidomycosis vs Asymptomatic Workers,[a] OR (95% CI)	Clinical Coccidioidomycosis vs Asymptomatic Workers and Symptomatic Noncases,[a] OR (95% CI)
All factors included in model			
Frequently performed soil-disturbing activities[b]	1.53 (0.85, 2.73)	1.56 (0.96, 2.61)	1.54 (0.92, 2.60)
Frequently in a dust cloud or storm[b]	5.93 (3.18, 11.06)	8.03 (4.73, 13.63)	4.11 (2.27, 7.44)
Frequently wore a respirator[c]	0.98 (0.44, 2.20)	1.03 (0.52, 2.04)	0.96 (0.47, 1.96)
Soil wetted frequently before soil-disturbing activity[c]	0.42 (0.24, 0.75)	NA[d]	0.67 (0.39, 1.15)

Note. CI = confidence interval; NA = not available; OR = odds ratio. Logistic regression reference groups were "infrequently."
[a]Sensitivity analyses.
[b]Frequently (every day or once a week), infrequently (rarely or never).
[c]Frequently (always or often), infrequently (sometimes, rarely, or never).
[d]Data on soil wetting were not systematically collected for confirmed cases and were not included in the multivariate analysis.

cloud or storm (Table 4) although wetting of soil could not be assessed in the confirmed case analysis because those data were not systematically collected from confirmed cases.

DISCUSSION

In this study, we identified that, within a construction setting in a coccidioidomycosis-endemic area, performing soil-disturbing activities and, specifically, active digging, working in a ditch or trench, and operating heavy machinery, were associated with clinical coccidioidomycosis. However, the factor most strongly associated with clinical coccidioidomycosis was frequently being in a dust cloud or storm. Even in the multivariate model, the odds of clinical coccidioidomycosis were 5.93 times greater for those who frequently versus infrequently reported being in a dust cloud or storm. The coccidioidomycosis risk of construction work in arid, endemic regions is likely partially attributable to work activities that generate dust but also to blowing dust. Therefore, in a dust storm in an endemic area, all workers regardless of job activity are at risk. We recommended that employers on these sites implement and enforce criteria for suspending work on the basis of wind and dust conditions.[13]

Frequently wetting the soil before disturbance was protective in the clinical case bivariate and multivariate analyses. The low prevalence of personal safety practice use, such as frequently wearing a respirator (12.5%) and changing into clean clothes before leaving work (4.6%), limited our ability to evaluate their effectiveness in preventing clinical coccidioidomycosis. However, soil disturbance was only significantly associated with clinical coccidioidomycosis in those who reported infrequently wearing a respirator, suggesting that frequently wearing a respirator is protective when one is conducting soil-disturbing activities. Although frequently washing up before lunch and at the end of the work shift were significantly protective in the clinical case analysis, they were not significantly protective in the sensitivity analyses. Further study is needed to understand the effectiveness of these measures.

Although some differences existed between our primary analysis and sensitivity analyses, frequent exposure to a dust cloud or storm remained significantly associated with clinical coccidioidomycosis in both multivariate sensitivity analyses. In addition, in both bivariate sensitivity analyses, frequent soil disturbance was a significant risk factor and, in the symptomatic noncases sensitivity analysis, wetting soil was significantly protective. Small numbers in the confirmed case analysis made assessing significance challenging. Because the symptomatic noncases group likely includes a substantial number of mild coccidioidomycosis cases, adding that group to our asymptomatic workers would bias results toward the null.

In this investigation, we identified 89 solar farm construction workers with clinically suspect coccidioidomycosis that was not laboratory confirmed. This is more than twice as many as the 44 workers with laboratory-confirmed coccidioidomycosis identified earlier.[13] The workers meeting our clinical case definition had similar clinical characteristics as laboratory-confirmed case-patients but less severe disease with fewer reports of weight loss, rash or skin lesions, and missed work; the lesser severity of these symptoms might partly explain why they did not get diagnosed. More than 100 additional workers had symptoms suggestive of coccidioidomycosis but did not meet all clinical case definition criteria. Missed work was reported by nearly all confirmed case-patients, almost half of those with clinical coccidioidomycosis, and 28% of the symptomatic noncases. Illness of this severity could have a substantial effect on workers' ability to maintain a quality job performance, retain their job, and provide for themselves and their families.

Although the odds of having clinical coccidioidomycosis did not differ between solar farms A and B, there was a significant association between employment at solar farm A and being a confirmed case. This association might be attributable to several differences at the 2 sites including standardized record keeping of confirmed coccidioidomycosis case-patients at solar farm A but not solar farm B, availability of onsite medical staff for consultation, variations in employee coccidioidomycosis trainings, respirator availability, and use of water for wetting soil before disturbance.

Limitations

This study had several limitations. We received responses from only 15.6% of the workers who were mailed questionnaires and had a higher response rate at solar farm A (20.5%) than at B (13.6%). It is probable that those who recalled having a coccidioidomycosis-like illness during employment were more likely to complete a questionnaire and to report dust exposure than those without illness, thus biasing our sample to overestimate the percentage of workers with clinical coccidioidomycosis and biasing our results toward an association between dust exposure and illness.

In addition, asymptomatic workers might have been more likely to forget or deny exposures. Including symptomatic noncases with asymptomatic workers for our sensitivity analysis may have helped control for this bias, and we found nearly all of the same major associations. Attaining laboratory confirmation was not possible because of logistical and resource constraints. Moreover, with the currently available serological testing, only recent infections could have been identified.

Coccidioidomycosis symptoms vary widely and many are nonspecific, which made it difficult to develop a reliable clinical case definition. To compensate, we used a specified clinical case definition and provided the sensitivity analysis comparing confirmed and asymptomatic workers. The inclusion criteria of feeling sick for 4 weeks or longer with specific symptoms likely excluded workers who had influenza or other common respiratory infections that are of typically shorter duration. However, this may have also excluded workers with mild coccidioidomycosis disease. In addition, as approximately 60% of coccidioidomycosis infections are asymptomatic, some of the asymptomatic workers may have had coccidioidomycosis; however, this would bias our results toward the null.

The racial/ethnic distribution of our sample may not have accurately represented the worker population because questionnaire response was voluntary. Lastly, questionnaires were distributed in English only and may have excluded those whose primary language was Spanish, although employer and union representatives reported that almost all workers were proficient in English.

Public Health Implications

This is one of few epidemiological investigations to identify an association between clinical coccidioidomycosis and outdoor construction work, including soil-disturbing work tasks and exposure to windblown dust, in an endemic area. Being outside in a dust cloud or storm was associated with clinical coccidioidomycosis risk regardless of work activities. This is the first study to find a protective association between clinical coccidioidomycosis and soil wetting before digging and a suggestive association between clinical coccidioidomycosis and infrequent use of a respirator when performing soil-disturbing activities.

Coccidioidomycosis risk should be considered during the planning of any construction work in endemic regions, and methods for controlling dust onsite along with personal safety measures for individual workers, including respirator use in the context of a written respiratory protection program, should be considered. Workers should be educated about their risk of developing coccidioidomycosis, how to identify and report symptoms, and the potential severity of resulting disease, and employers should follow Occupational Safety and Health Administration injury and illness reporting requirements.

In addition, workers should be informed about how to receive clinical evaluation by utilizing the workers' compensation system and employer-provided health care at least initially, and how to get appropriate treatment and follow up from a provider who is familiar with coccidioidomycosis. Lastly, it is important for primary care, emergency, and occupational medicine providers to have increased awareness of coccidioidomycosis, to inquire about work activities and soil disturbance in coccidioidomycosis-endemic areas when they are seeing patients with symptoms suggestive of coccidioidomycosis, and to report suspected cases to local health authorities per state reporting requirements. AJPH

CONTRIBUTORS

All of the authors contributed to the conceptualization and design of this epidemiological investigation, provided substantial input on data analysis, and assisted in drafting and critical review of the article. G. L. Sondermeyer Cooksey, J. A. Wilken, and D. J. Vugia led the efforts to design the investigation and data analysis. G. L. Sondermeyer Cooksey performed all data analysis and led the drafting of the article.

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HUMAN PARTICIPANT PROTECTION

This outbreak investigation was conducted as public health practice and did not require institutional review board approval.

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