Short-term Effects of Wood Smoke Exposure on the Respiratory System Among Charcoal Production Workers*

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Study objectives: We aimed to investigate the short-term respiratory effects of heavy, occupational wood smoke exposure among traditional charcoal production workers.

Patients and setting: A total of 22 charcoal workers (mean age, 41 years; 9 current smokers, 5 ex-smokers, and 8 nonsmokers) were studied and compared with a control group of 35 farmers residing in Perama, Rethymnon, Crete.

Results: The charcoal workers were exposed to wood smoke for an average of 14 h/d during a mean of 23.7 days required for the burning of kilns. The workers under study were found to have significantly more cough (odds ratio [OR], 4.8; 95% confidence interval [CI], 1.2 to 19.7), sputum production (OR, 6; 95% CI, 1.4 to 26.5), wheezing (OR, 7.7; 95% CI, 1.4 to 41.5), dyspnea (OR, 28.7; 95% CI, 5.4 to 153), and hemoptysis (OR, 2.7; 95% CI, 0.7 to 55) than the control group. The prevalence of respiratory symptoms such as cough, sputum production, wheezing, and dyspnea in the charcoal workers was significantly elevated during the exposure period (OR, 5.4; 95% CI, 1.1 to 17.7; OR, 5.7; 95% CI, 1 to 31; OR, 9.8; 95% CI, 1 to 88; and OR, 36.7; 95% CI, 1 to 327, respectively). The mean ± SD percent of predicted values of FVC, FEV₁, FEV₁/FVC ratio, and forced expiratory flow at 25 to 75% of FVC during the exposure period were significantly lower than those before exposure: 106 ± 10.8 vs 101 ± 11.9, p < 0.01; 104 ± 16 vs 97 ± 15, p < 0.001; 81 ± 9 vs 78 ± 8, p < 0.001; and 95 ± 27 vs 80 ± 25, p < 0.01, respectively. The mean ± SD value of peak expiratory flow at midday and in the evening during the exposure were significantly lower than before: 524 ± 131 L/min vs 548 ± 108 L/min, p = 0.03; and 521 ± 135 L/min vs 547 ± 131 L/min, p = 0.02, respectively.

Conclusions: Our results suggest that wood smoke exposure in charcoal workers is associated with increased respiratory symptoms and decreased pulmonary function. Longitudinal studies are needed to determine potential long-term adverse respiratory effects.

Key words: charcoal production; occupational exposure; wood smoke

Abbreviations: CI = confidence interval; FEF₂₅–₇₅ = forced expiratory flow at 25 to 75% of FVC; OR = odds ratio; PEF = peak expiratory flow; PFT = pulmonary function test; RADS = reactive airway dysfunction syndrome

Few reports in the literature have evaluated the association between occupational wood smoke exposure and respiratory disease. Most of them have investigated the effects of smoke exposure in forest firefighters. Smoke components in wildland fires, including CO, aldehydes, respirable particulates, and semivolatile and volatile organic fractions, can cause short-term and long-term adverse respiratory effects. Studies of forest firefighters have demonstrated both short-term and long-term changes in their pulmonary function. Short-term changes, including reductions in spirometric parameters and increased airway reactivity, have been described after fire fighting, although they have generally been transient and have occurred when respiratory protection was not used during exposure periods. In
longitudinal studies of firefighters in the 1960s and 1970s, Peters and coworkers7 and Sparrow and colleagues8 demonstrated accelerated declines in spirometric parameters in Boston firefighters, most likely as a result of exposure to products of combustion, and a similar trend was found in London firemen.9 Other studies10,11 have been investigating the role of indoor pollution of household cooking using biomass fuels, including wood fuel. The association between indoor air pollutants because of firewood usage and the development of COPD has been confirmed among elderly women in Bogota.10 Moreover, increasing exposure to domestic wood smoke has been associated with chronic bronchitis.12

Open charcoal production is a traditional seasonal job still existing in certain rural areas in Crete. Charcoal production is the process of pyrolyzing wood under controlled conditions to produce charcoal. It involves cutting wood, assembling it into cone-shaped piles, covering it with soil, and, finally, letting it burn until charcoal is produced. Kiln sizes vary between 15 m³ and 90 m³. Many of the tasks involved could be regarded as potentially hazardous. During the burning period of production, workers are exposed to incomplete combustion of wood burning and noxious smoke gases for several hours per day. In this study, we investigated the short-term respiratory effects of occupational heavy wood smoke exposure in these traditional charcoal workers. To the best of our knowledge, there has been no study in the literature investigating the short-term respiratory effects of this occupational exposure.

Materials and Methods

Subject Selection

The survey was carried out in the villages around the area of the valley of Perama, Rethymnon, Crete. The study population was selected by local town hall officials, from among 32 active charcoal workers. A total of 22 male workers (9 current smokers, 5 ex-smokers, and 8 nonsmokers; mean ± SD age, 41.2 ± 16 years) agreed to participate in the study. Using the records from the local municipal role, 35 male residents of the studied area (14 current smokers, 9 ex-smokers, and 12 nonsmokers; mean age, 44.2 ± 20 years) not working in charcoal production were randomly selected to participate as a control group. The study was approved by the hospital ethics committee, and all subjects gave their informed consent.

Study Design

The study involved three visits that took place in the local rural medical offices. At the first visit, a history (including questions on occupational exposure) was taken and a physical examination and spirometry were performed. All subjects completed a self-administered Greek version of the internationally accepted British Medical Research Council respiratory questionnaire,13 supplemented with questions on work-related symptoms. Symptoms were considered as work related if subjects reported them as being provoked by contact with relevant respirable agents during the working period. At the same visit, the charcoal workers were instructed to perform peak expiratory flow (PEF) measurements and complete a diary card with their respiratory symptoms and PEF measurements. Details of the exposure to wood smoke in the kilns, such as hours per day of exposure, were also recorded in the diary. At the second visit, which took place after 10 to 14 days of exposure, a check of the diaries was done and a second spirometry was performed. Finally, during the third visit, a reassessment of the subjects, including a respiratory physical examination, took place and the diaries were collected.

Symptoms, Spirometry, and PEF Measurements

Spirometry was performed by a trained technician, using a calibrated pneumotachograph spirometer (Flowmate, Version E2.0; Jaeger; Wuerzburg, Germany). The device was calibrated daily, and the values were recorded at body temperature pressure, saturated. Each subject completed a dynamic spirometry with at least three acceptable and two reproducible maneuvers according to standard guidelines.14 Predicted values were obtained from the new standardized lung function testing guidelines of the European Community for Steel and Coal Luxembourg 1993.14 All data were expressed as percentages of predicted values. PEF was measured using a peak flowmeter (Mini Wright; Armstrong Medical Industries; Lincolnshire, IL) three times daily, at 7 AM, 2 PM, and 8 PM. Each subject recorded morning, midday, and evening PEF readings (three blows for each measurement) for the 2-week period before exposure and during the period of exposure. The morning PEF measurement during the exposure period was performed just before starting work. Participants were instructed to record the highest of the three PEF readings in the diary card. The PEF was expressed as measured (liters per minute) and as a percentage of the subjects’ maximal values during the study period. Any respiratory symptoms were also recorded. Symptoms noted in the diary were cough, wheezing, sputum production, dyspnea, and hemoptysis.

Statistical Analysis

The data were analyzed as prevalence odds ratios (ORs) for the presence of various respiratory symptoms among the charcoal workers before and during the exposure period and between the charcoal workers and the control group. Paired Student’s t test was used to compare the variables before and during the exposure period. A Mann-Whitney U test was drawn to compare the mean values of spirometric variables, PEF measurements, and symptom scores between workers and control group. A nonparametric Wilcoxon signed-rank test was used to compare proportions. For all statistical tests, a probability of 0.05 was taken as significant. All analyses were performed using software (SPSS 6.0 for Windows; SPSS; Chicago, IL).

Results

Exposure

A mean of 23.7 ± 4.6 days (range, 15.2 to 28.4 days) was required for the kilns to be burned. The burning period represents the actual exposure time. The charcoal workers under study were exposed to the wood smoke of burning kilns for a relatively long
period of time every day (14.1 ± 6.4 h) starting at 7 AM, as they were tending closely the pyrolyzing procedure of the burning kilns. No respiratory protective equipment was used by the workers at any time during the burning period of the kilns.

Symptoms

ORs and their associated 95% confidence intervals (CIs) for the prevalence of various respiratory symptoms in the control group and in the charcoal workers are shown in Table 1 (Wilcoxon signed rank test). The workers had significantly elevated ORs during the exposure period for symptoms such as cough (OR, 4.8), sputum production (OR, 6.0), wheezing (OR, 7.7), dyspnea (OR, 28.7), and hemoptysis (OR, 12.7; Table 1). All workers complained of headache, and acute eye, nose, and throat irritation during the exposure period. Table 2 shows the ORs and 95% CIs for the prevalence of respiratory symptoms in the workers before and during the exposure period (Wilcoxon signed-matched-pairs rank test). During the exposure period, the workers had significantly elevated ORs for the respiratory symptoms: cough (OR, 4.5), sputum production (OR, 5.7), wheezing (OR, 9.8), and dyspnea (OR, 36.7). There was a trend to have more symptoms when the workers spend more time tending the pyrolyzing procedure, but this trend was not significantly different. Nonsignificantly elevated ORs were found for hemoptysis (OR, 8.0). Findings of a complete checkup of workers with hemoptysis, including bronchoscopy, sputum cytology with microbiology, and CT of the chest, were negative for malignancy or infection. Bronchoscopy showed no active bleeding. Endoscopic findings of subacute bronchitis were observed. In one worker, high-resolution CT showed bronchiectases in the left upper lobe. All three workers were current smokers. Symptoms in current smokers and nonsmokers did not differ in response to wood smoke.

Spirometry and PEF Measurements

The mean ± SD values of pulmonary function tests (PFTs) in charcoal workers before and during the exposure period are shown in Figure 1. The mean percent of predicted value of FVC during the exposure period was significantly lower than that before (106 ± 10.8 vs 101 ± 11.9, p < 0.01; Fig 1); the same was true regarding FEV1 (104 ± 16 vs 97 ± 15, p < 0.001), FEV1/FVC ratio (81 ± 9 vs 78 ± 8, p < 0.001), and forced expiratory flow at 25 to 75% of FVC (FEF25–75%) [95 ± 27 vs 50 ± 25, p < 0.01; Fig 1]. The percentage declines in PFT results before and during exposure corresponded to a mean ± SD of 157 ± 32 mL for FVC, 196 ± 24 mL for FEV1, and 4 ± 1.1 L/s for FEF25–75%.

The mean PEF values of the charcoal workers in the morning, at midday, and in the evening before and during the exposure period are shown in Figure 2. The mean value of PEF at midday during the exposure period was significantly lower than before (524 ± 131 L/min vs 548 ± 108 L/min, p = 0.03). Similarly, the mean value of PEF in the evening was significantly lower during the exposure period than before (521 ± 135 L/min vs 547 ± 131 L/min, p = 0.02). The mean values of PEF in the morning were lower during the exposure than before, but this difference did not reach statistical significance (511 ± 120 L/min vs 527 ± 152 L/min, p = 0.07). Current smokers’ responses to wood smoke either in spirometry or in PEF were not significantly different from those of nonsmokers.

Discussion

Charcoal production is a traditional occupation in which the short-term respiratory effects have never been studied. This study shows that wood smoke exposure is associated with increased odds of self-reported respiratory symptoms, including cough, sputum production, wheezing, and dyspnea. Furthermore, short-term decrements in PFT measures were found to accompany the increased symptom prevalence during the exposure period.

The charcoal workers had an short-term postexposure decline in PFT indexes, including FVC, FEV1, FEV1/FVC ratio, and FEF25–75%. The exposure of the population studied is somewhat similar to the

Table 1—Prevalence of ORs for Work-Related Symptoms in Control Subjects and Charcoal Workers During Wood Smoke Exposure

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Control Subjects</th>
<th>Workers</th>
<th>OR (95% CI)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cough</td>
<td>6 (17)</td>
<td>11 (50)</td>
<td>4.8 (1.2–19.7)</td>
<td>0.008</td>
</tr>
<tr>
<td>Sputum production</td>
<td>3 (8.6)</td>
<td>8 (36)</td>
<td>6.0 (1.4–26.5)</td>
<td>0.009</td>
</tr>
<tr>
<td>Wheezing</td>
<td>2 (6)</td>
<td>7 (32)</td>
<td>7.7 (1.4–41.5)</td>
<td>0.008</td>
</tr>
<tr>
<td>Dyspnea</td>
<td>2 (6)</td>
<td>14 (64)</td>
<td>28.7 (54–153)</td>
<td>0.004</td>
</tr>
<tr>
<td>Hemoptysis</td>
<td>0 (0)</td>
<td>3 (8.5)</td>
<td>12.7 (0.7–55)</td>
<td>0.02*</td>
</tr>
</tbody>
</table>

*aOne-tailed probability.*
exposure to smoke produced by fires in the open country (wildland fires). Charcoal workers, like wildland firefighters, are exposed to several vegetative resinous combustion products, including CO, aldehydes, acids, respirable particulates, and semivolatile and volatile organic agents. Moreover, exposure patterns and work practices have remarkable similarities in both occupations. Suppression activities in open-country and forest fires have a potential for long uninterrupted periods of exposure to smoke.

In this study, the workers were exposed to wood smoke for a long time, approximately 9 to 19 h/d for a total of 2 to 4 weeks. Taking into account the similarities between the exposures of wildland firefighters and charcoal workers, we could compare our data with the studies on firefighters working in forest fires. Five previous cross-seasonal studies of wildland firefighters have reported similar PFT declines associated with recent fire-fighting activities and smoke exposure. Our findings are in accordance with the PFT measure decline seen in these studies, but the magnitude of the decline in PFT measures of the population in our study is generally greater than in the studies of firefighters.

The California Department of Health Services study found mean individual declines for FVC, FEV₁, and FEF₂₅–₇₅% of 90 mL, 150 mL, and 0.44 L/s, respectively. The Johns Hopkins University study found that FVC and FEV₁ declined by 130 mL and 101 mL, respectively, in the group classified in the highest exposure category, which averaged 73 h of fire fighting. The PFT decrements of charcoal workers were 157 mL for FVC, 196 mL for FEV₁, and 4.4 L/s for FEF₂₅–₇₅%, and are comparable to those of wildland firefighters in the highest exposure categories (heavier and more prolonged exposure period). We should also note that the charcoal workers never used respiratory protective equipment at any time during the burning period of the kilns.

In addition to the dynamic spirometric changes, a significant postexposure decline of maximal expiratory flow rate (PEF) was observed in charcoal workers. Our results are in agreement with the data of Thomas, who reported a statistically significant decrease in several pulmonary indexes, including PEF, after fire fighting. The mean postexposure PEF changes in this study were 16 L/min, 24 L/min,

### Table 2—Prevalence of ORs for Respiratory Symptoms in Charcoal Workers Before and During Exposure

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Charcoal Workers, No. (%)</th>
<th>OR (95% CI)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cough</td>
<td>4 (18)</td>
<td>11 (50)</td>
<td>4.5 (1.1–17.7)</td>
</tr>
<tr>
<td>Sputum production</td>
<td>2 (9)</td>
<td>8 (36)</td>
<td>5.7 (1–31)</td>
</tr>
<tr>
<td>Wheezing</td>
<td>1 (4.5)</td>
<td>7 (32)</td>
<td>9.8 (1–88)</td>
</tr>
<tr>
<td>Dyspnea</td>
<td>1 (4.5)</td>
<td>14 (64)</td>
<td>36.7 (1–327)</td>
</tr>
<tr>
<td>Hemoptysis</td>
<td>0 (0)</td>
<td>3 (8.5)</td>
<td>8.0 (0.4–34.4)</td>
</tr>
</tbody>
</table>

**Figure 1.** Mean (± SD) values of spirometric indexes of charcoal workers before and during the exposure period. * = p < 0.01; ** = p < 0.001.

**Figure 2.** The individual morning, midday, and evening PEF values of charcoal workers before (open circles) and during (solid circles) exposure. Solid bars represent mean (± SD) values. NS = not significant.
and 26 L/min for morning, midday, and evening measurements, respectively. The PEF decline has a tendency to be greater at midday and evening. This diurnal pattern of the PEF decline may reflect that the flows were affected by the exposure time during the day. Alternatively, the decreases in flows may have been partly reversed after a relatively short period of cessation of exposure to irritants during the previous night. The data of the present study are not enough to differentiate between these two hypotheses. Moreover, it should be noted that the study was not designed to evaluate either the association between the magnitude of exposure and the pulmonary function changes or the reversibility of short-term pulmonary changes after cessation of the exposure to smoke irritants. There has been an ongoing longitudinal study of our cohort of charcoal workers for 3 years now, aiming to determine whether the short-term decrements in lung function seen in this study are causing long-term chronic respiratory effects. These long-term effects have been reported in studies of wildland firefighters and in studies of indoor firewood smoke exposure.

An increase in reports of respiratory symptoms accompanying the decreases seen in lung function across the work shift was observed in this study. Studies of wildland firefighters showed similar cross-season changes in prevalence in one or more respiratory symptoms. In the study of Serra et al., an increased prevalence of cough and sputum production long after the fire-fighting season was reported.

We should emphasize the observed hemoptysis in three workers. On bronchoscopy, a subacute bronchitis was found. Subacute bronchitis because of the heavy wood smoke exposure may explain the increased lower respiratory tract symptoms observed in this study. We do not know whether the bronchiectasis diagnosed in one of the workers was related to long-term wood smoke exposure or was simply an incidental finding.

The mechanisms underlying the increased respiratory symptoms and lung function abnormalities to wood smoke exposure are uncertain. Wood and vegetative combustion materials emit smoke with a variety of respiratory irritants and noxious agents, such as CO, aldehydes, acids, SO2, NO2, respirable particulates, and semivolatile and volatile organic agents. Certain characteristics of the work, such as extended work demands, leading to long work shifts and increased breathing rate, enhance the toxic effects of the noxious agents on the respiratory system. High CO levels in wood smoke of open kilns have been detected in the Zambia study by Ellegard. Moreover, studies on wildland firefighters found levels of COHb to be from 5 to 9%. Inhalation of CO in combination with combusted particulates produces headaches, nausea, sore throat, and irritation. Complaints of daily headache and irritation were reported from all charcoal workers in this study. It has also been reported that aldehydes and acids reduce the ciliary activity of the respiratory tract, interfering with the ability of the airway epithelium to remove particles and microorganisms. This may explain the increased cough and sputum expectoration seen in charcoal workers. Moreover, several air pollutant components of wood smoke, such as SO2, NO2, and particulates, have been reported to increase respiratory symptoms and to affect lung function even in low concentrations. High concentrations of irritant gases have been reported to cause pulmonary symptoms resembling asthma, a condition known as reactive airway dysfunction syndrome (RADS). Moreover, a short-term increase of airway responsiveness has been reported in firefighters. We suspected RADS in two workers with a large PEF decrease (Fig 2). Unfortunately, methacholine challenge was not applied in this study in order to assess airway hyperresponsiveness. Thus, it is unclear if these two workers in fact had RADS.

In conclusion, both increased respiratory symptoms and worsening of lung function found in this study indicate a short-term cross-season and mid-season effect associated with smoke exposure because of the pyrolyzing of wood to produce charcoal. The changes in lung function seen in this study should be of concern for potential long-term adverse respiratory effects in charcoal workers. Longitudinal studies are needed to determine the long-term effects on the respiratory system in this traditional occupation.

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