Small mine size is associated with lung function abnormality and pneumoconiosis among underground coal miners in Kentucky, Virginia and West Virginia

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ABSTRACT
Objective To describe the prevalence of lung function abnormality and coal workers’ pneumoconiosis (CWP) by mine size among underground coal miners in Kentucky, Virginia and West Virginia.

Methods During 2005–2012, 4491 miners completed spirometry and chest radiography as part of a health surveillance programme. Spirometry was interpreted according to American Thoracic Society and European Respiratory Society guidelines, and radiography per International Labour Office standards. Prevalence ratios (PR) were calculated for abnormal spirometry (obstructive, restrictive or mixed pattern using lower limits of normal derived from National Health and Nutrition Examination Survey (NHANES) III) and CWP among workers from small mines (≤50 miners) compared with those from large mines.

Results Among 3771 eligible miners, those from small mines were more likely to have abnormal spirometry (18.5% vs 13.8%, p<0.01), CWP (10.8% vs 5.2%, p<0.01) and progressive massive fibrosis (2.4% vs 1.1%, p<0.01). In regression analysis, working in a small mine was associated with 37% higher prevalence of abnormal spirometry (PR 1.37, 95% CI 1.16 to 1.61) and 2.1 times higher prevalence of CWP (95% CI 1.68 to 2.70).

Conclusions More than one in four of these miners had evidence of CWP, abnormal lung function or both. Although 96% of miners in the study have worked exclusively under dust regulations implemented following the Federal Coal Mine Safety and Health Act, we observed high rates of respiratory disease including severe cases. The current approach to dust control and provision of safe work conditions for central Appalachian underground coal miners is not adequate to protect them from adverse respiratory health effects.

INTRODUCTION
Following decades of decline, the prevalence of coal workers’ pneumoconiosis (CWP) among active US underground coal miners has been increasing since the late 1990s.¹⁻³ Data from miners participating in the National Institute for Occupational Safety and Health (NIOSH)-administered Coal Workers’ Health Surveillance Program (CWHSP) suggest that the current prevalence of CWP among underground miners with long mining tenures is approximately double its 1995–1999 low point. The prevalence of progressive massive fibrosis (PMF), the severe form of CWP, has more than quadrupled since the 1980s among central Appalachian underground coal miners.¹⁴ Currently, nearly all active coal miners with CWP have worked exclusively under dust standards implemented following the Federal Coal Mine Health and Safety Act of 1969, suggesting that miners still lack adequate protection from coal mine dust (CMD)-related disease.⁵

Hypothesised factors contributing to increases in CWP prevalence include changes in mining practices, inadequate enforcement of current dust standards, longer work hours and increased exposure to crystalline silica.⁶⁻⁸ Recognition of geographic clusters of rapidly progressive CWP, most notably in Kentucky, Virginia and West Virginia, indicates that this region may shoulder a disproportionate burden of disease.⁹ Identification of these clusters was an important step, but it remains unclear as to what underlying factors are driving CWP disparities. Mine size (number of underground miners...
employed) has recently been identified as a predictor of CWP risk among US underground coal miners.10–12 As a result, NIOSH has used targeted surveillance to focus on workers from small underground mines.13

The Enhanced CWHSP (ECWHSP) was started in 2005 by NIOSH in collaboration with the Mine Safety and Health Administration (MSHA). The original objectives of the ECWHSP were to target regions with clustering of rapidly progressive CWP and low participation in the Coal Workers’ X-ray Surveillance Program (CWXSP), an existing component of the CWHSP.13 Miners participating in ECWHSP provide occupational histories, and are offered spirometry, a measure of lung function, in addition to a chest radiograph. Spirometry data are an important addition to the surveillance programme because exposure to CMD has been linked to lung function impairment, which can cause substantial morbidity independent of radiographic evidence of CWP.14–16 In the absence of biomarkers for CWP, spirometric testing can complement chest radiography as a useful tool to help clinicians monitor the health status of coal miners, perhaps enhancing the potential for intervention to preserve respiratory health.6,7,17 The goal of this study is to characterise the prevalence of lung function abnormality and CWP by mine size among active underground coal miners working in Kentucky, Virginia and West Virginia.

METHODS
Participants
Analysis was restricted to active underground coal miners participating in the ECWHSP during September 2005–December 2012. Although the ECWHSP targeted geographic regions using the aforementioned criteria, all coal miners, current and former, were welcome to be screened at the mobile unit. As of December 2012, ECWHSP had participants from 15 states, but we restricted analysis to Kentucky, Virginia and West Virginia because of the limited sample size (n=254) from small mines outside these three states. ECWHSP is a surveillance programme with non-research designation, and is exempt from NIOSH Human Subjects Review Board approval (11-DRDS-NR03). Prior to screening, participants signed a consent form acknowledging their confidential participation in a health surveillance programme. For miners with multiple ECWHSP encounters, only the most recent visit was used.

Chest radiography and spirometry testing
Chest radiographs and spirometry were administered by trained technicians in a NIOSH mobile examination unit. Radiographs were interpreted by a minimum of two NIOSH-approved physician B Readers,18 and lung parenchymal abnormalities consistent with CWP were classified using the International Labour Office (ILO) Guidelines for the Use of the ILO International Classification of Radiographs of Pneumoconioses.19 Presence of CWP was defined as profusion of small pneumoconiotic opacities ILO subcategory 1/0 or above (possible range: 0/0–3/+), and PMF was defined as the presence of large (>1 cm) pneumoconiotic opacities (category A, B or C).19

Spirometry was administered by NIOSH-trained technicians using a dry-rolling seal spirometer and interpreted using American Thoracic Society and European Respiratory Society guidelines.20,21 Lower limits of normal (LLN) for forced expiratory volume in 1 s (FEV₁), forced vital capacity (FVC), and the ratio FEV₁/FVC, which characterises the proportion of the miner’s vital capacity expelled in the first second of expiration, were calculated using sex and race/ethnicity-specific prediction equations derived from data collected during the Third National Health and Nutrition Examination Survey (NHANES).22 Per cent predicted values for FEV₁ and FVC were also calculated. Patterns of abnormality were defined as obstructive, restrictive or mixed, as follows23:

- Obstructive pattern: FEV₁/FVC<LLN; and FVC>LLN; and FEV₁<LLN
- Restrictive pattern: FEV₁/FVC>LLN; and FVC<LLN
- Mixed pattern: FEV₁/FVC<LLN; and FVC<LLN

Abnormal lung function, as an analytic outcome variable in the following analysis, is defined as the presence of one of the above three patterns.

Miner demographics, underground mining tenure, smoking status (defined as a miner reporting ever being a smoker) and body mass index (BMI) were calculated using data provided by the miner in the mobile examination unit. Mining plans submitted by mines to MSHA were used to determine the number of underground miners by location for the year the miner participated in the ECWHSP. For consistency with earlier work, mines with 50 or fewer underground employees were classified as ‘small’ and those with more than 50 were classified as ‘large’.10

Statistical analysis
Data were analysed using SAS V9.3 (SAS Institute, Cary, North Carolina, USA). Crude comparisons of worker characteristics by mine size were assessed using the χ² test (for dichotomous variables) and the t test (for continuous variables). Log-binomial regression models with response variables characterising abnormal lung function and CWP status were fit to ECWHSP data. These models allowed unbiased estimation of adjusted prevalence ratios (PR) for abnormal spirometry and a determination of CWP among those working in small mines, compared with counterparts in large mines.24,25

RESULTS
Descriptive characteristics
From September 2005 to December 2012, 8980 underground miners completed visits to the ECWHSP mobile unit; 4491 of these worked in Kentucky, Virginia or West Virginia. After excluding former miners, miners with fewer than two acceptable spirometry curves indicating maximum effort, and duplicate observations (ie, those with more than one ECWHSP encounter during the time period), 3771 remained. Less than 3% of the otherwise eligible sample was excluded due to invalid spirometry results. The 3771 miners ranged from 18 to 74 years of age. The mean and median mine sizes were 200 and 97 employees, respectively. Descriptive characteristics are summarised in table 1. There was no statistically significant difference (α=0.05) between those working in small mines and those in large mines by sex, race or underground mining tenure. Those from large mines were on average 1 year older, and had a slightly higher BMI. Those from small mines were more likely to report ever smoking.

Spirometry results
A total of 551 (14.6%) miners had abnormal (obstructive, restrictive or mixed pattern) spirometry results (table 2). The overall prevalence of abnormal spirometry was higher among workers from small mines (18.5% vs 13.4%). Those from small mines had significantly higher prevalence of obstructive and mixed abnormalities, but there was no significant difference by mine size among those with a restrictive abnormality. Mean

FEV₁/FVC and per cent predicted values for FEV₁ and FVC were lower among workers from small mines.

Chest radiograph results
Radiographic evidence of CWP was found in 6.5% (n=246) of miners screened; 53 (1.4%) had PMF. The prevalence of CWP was higher among workers from small mines (10.8% vs 5.2%, table 2). Examining the data by small opacity profusion category, there were significant differences in prevalence by mine size for categories 1 and 2, but not category 3. The prevalence of PMF was also higher among those from small mines (2.4% vs 1.1%).

Adjusted results
Abnormal spirometry
Table 2 includes results from log-binomial regression models with spirometry results (normal/abnormal) as the binary response. Controlling for underground mining tenure, BMI and smoking status, working in a small mine was associated with 37% higher prevalence of abnormal spirometry compared with working in a large mine (PR 1.37, 95% CI 1.16 to 1.61).

Miner age and underground mining tenure are known factors associated with CWP. Because age and mining tenure are highly correlated, simultaneous inclusion of these variables in multiple regression models could lead to model instability due to multicollinearity. Because the ECWHSP collects high-quality work histories, PRs presented here are tenure adjusted. However, when testing the impact of using age instead of underground tenure during model development, the adjusted PR for those from small mines changed minimally, suggesting that the overall magnitude of effect does not hinge greatly on whether age or tenure is used.

Presence of CWP
The association between mine size and presence of CWP is summarised in table 2. Controlling for underground mining tenure and smoking status, those working in small mines were two times more likely to have CWP than those in large mines (PR 2.13, 95% CI 1.68 to 2.70). Substituting age in place of underground mining tenure resulted in minimal change to adjusted effect sizes.

Concurrent abnormal spirometry and CWP
Of the 246 miners with CWP 75 (30.5%) had abnormal spirometry, compared with 476 of 3525 (13.5%) miners without CWP. Thus, the prevalence of abnormal spirometry among those with radiographic evidence of CWP was 2.3 times higher than among those without CWP (p<0.01). Compared with those from large mines, workers from small mines had 2.5 times higher prevalence of concurrent abnormal spirometry and a determination of CWP (PR 2.48, 95% CI 1.58 to 3.88, figure 1). Less than 1% (3/
been associated with declines in FEV1 among US underground
smoking status. Exposure to CMD, high BMI and smoking have
from small mines, after controlling for tenure, BMI and
mate adjusted PR.

Figure 1  The relationship between abnormal spirometry and
radiographic evidence of coal workers’ pneumoconiosis among
Kentucky, Virginia, and West Virginia underground coal miners, by
mine size, Enhanced Coal Workers’ Health Surveillance Program

3696) of miners had PMF in the absence of abnormal spirometry,
while 29.3% (22/75) of miners with abnormal spirometry and
CWP were found to have PMF.

DISCUSSION
To the best of our knowledge, this is the first study to character-
ise the prevalence of abnormal lung function among coal miners
with respect to mine size. Previous work documented a high
prevalence of CWP among coal miners working in small mines, but
this was prior to NIOSH’s surveillance focus on ‘hot spots’
and areas where small mines predominate.9 10 11 Although we
focused on three states, these results are generally consistent
with findings from earlier work examining the association
between mine size and CWP; we incorporated additional data
from targeted surveillance and used regression methods to esti-
mate adjusted PR.

Within Kentucky, Virginia and West Virginia, the prevalence
of abnormal spirometry was about 40% higher among workers
from small mines, after controlling for tenure, BMI and
smoking status. Exposure to CMD, high BMI and smoking have
been associated with declines in FEV1 among US underground
collectors.26 We were able to account for differences in BMI
and smoking, but did not have measured exposure data for
CMD. As will be discussed later, it is likely that CMD levels are
higher in small mines. Unmeasured factors, such as history of
childhood pneumonia, passive exposure to tobacco smoke, and
exposure to coal or wood smoke in the home, are also asso-
ciated with declines in lung function.26 Although it is possible
that these factors differ among workers based on mine size, they
are unlikely explanations for the observed differences. In a lon-
gitudinal study, Wang et al26 noted a tendency among workers
in small mines to have higher rates of FEV1 decline over an
average of 11 years, but the study had limited power (n=264)
and the difference was not significant. Although ECWHSP data
are not longitudinal, this large sample within Kentucky, Virginia
and West Virginia allows for prevalence estimates with improved
precision.

We observed a clear negative association between mine size
and the prevalence of CWP. These findings are consistent with
those reported by Laney and Artfield in 2010, although they
analysed CWXSP and ECWHSP data through 2009, prior to the
ECWHSP’s focus on small mines.27 Differences in work
practices and conditions leading to elevated CMD levels may be
associated with mine size, which could explain part of the rela-
tionship observed here. In addition, the practice of thin-seam
mining is common in Kentucky, Virginia and West Virginia and
it has been documented that thin seam mining involves drilling
through more quartz-bearing rock.27 As a result, miners are at
risk for exposure to high concentrations of respirable crystalline
silica in airborne dust. It may be that workers in these small
mines are exposed to relatively more CMD including more
silica dust as a result of differences in geological conditions,
equipment maintenance resources, work practices and ventila-
tion controls.

For a disease like CWP, which is irreversible and often diffi-
cult to identify, any practical means of early detection would be
a valuable tool for miners and their clinicians. Among coal
miners, periodic spirometry is recommended.14 Rapid lung
function declines have recently been documented among young
miners progressing to PMF.28 While we observed a relatively
low proportion of miners with abnormal spirometry results to
also have CWP, a high proportion of miners who did have con-
current abnormalities were diagnosed with PMF, the most
severe form of pneumoconiosis.

Individuals with chronic obstructive pulmonary disease (COPD)
often experience lung function impairment. Cigarette smoking is
the most common risk factor for COPD and the prevalence of
lung function impairment is three times higher among current
smokers compared with non-smokers.29 History of smoking is
common within the mining sector,30 but COPD can also result
from exposure to CMD, even among non-smokers and in the
absence of radiographic evidence of simple CWP.31 We found
14.9% of small mine workers and 11.9% of large mine workers to
have abnormal spirometry but no radiographic evidence of CWP.
Even with limited efficacy as an early detection tool for simple
CWP, periodic spirometry among coal miners could still play an
important role in monitoring their respiratory health.

Participation in the ECWHSP is voluntary, which could intro-
duce selection factors. A recent analysis found no evidence of
positive bias in the reported prevalence of CWP due to trends in
NIOSH surveillance programme participation, even after addi-
tion of the ECWHSP to the existing CWXSP.11 The authors
found that, if anything, NIOSH underestimates the prevalence
of CWP among US underground coal miners. Owing to a small
sample of active underground coal miners outside Kentucky,
Virginia, and West Virginia, we limited analysis to these three
states, and findings may not be generalisable to small mines in
other regions. However, current ECWHSP plans include an
intensified focus on recruitment from small underground coal
miners throughout the country to address this issue. We used
underground mining tenure as a surrogate for dust exposure.
Because CMD is the only cause of CWP, direct exposure ascer-
tainment would be ideal, but it was not possible in the current
study. A final rule recently issued by MSHA will require, by
2016, the use of continuous personal dust monitors to assess
exposures of underground coal miners in positions exposed to
the highest respirable dust concentrations in addition to miners
with evidence of pneumoconiosis.32 Unlike CWP, lung function
impairment has multiple causes. Therefore, it is difficult to
determine the proportion of the abnormalities observed among
this particular population attributable to occupational expos-
sures. The study was cross-sectional, and although unlikely, we
cannot rule out the possibility that a portion of the observed
small mine effect may be attributable to large mine operators’
ability to identify and exclude miners with pre-existing lung
function deficits or pneumoconiosis during pre-employment
screening. The choice of 50 underground employees for the
‘small’ mine size cut-off is arguable. The lower quartile values
of mine size for the entire sample and for CWP cases closely
bound 50. Given the distribution of these data and the
precedent established by previous research, we felt this cut-off was appropriate and practically meaningful, and that it would allow us to compare our findings to past work. Developing an ordinal or continuous predictor could be useful for future research on the mine size effect.

Practically all miners (>96%) included in this study have worked exclusively under CMD regulations established by the 1969 Coal Mine Health and Safety Act. Coal mining is a physically demanding profession, yet more than 19% of those screened had CWP, abnormal lung function or both. A significantly higher burden of respiratory disease was observed among workers from small mines. Mining practices have changed over time, and environmental and/or work-practice differences between small and large mines could influence exposure characteristics.

Within the context of what is now known about the resurgence of CWP and PMF in central Appalachia, these most recent findings are troubling, especially considering that PMF was nearly eliminated from the region during the 1990s.5 The recent resurgence of CWP and PMF in central Appalachia, these most significant characteristics.

A key component of the recent MSHA rule cause for scrutiny. A key component of the recent MSHA rule prepared with available historical standards, and the picture among workers in the smallest mines is even worse. There is no published standard with which to directly compare these lung function findings, but the realisation that 15% of this relatively young and working population had a spirometric abnormality is food for thought. A key component of the recent MSHA rule will soon require incorporation of lung function testing into all NIOSH coal miner (underground and surface) respiratory health surveillance activities.2,3 These results remind us that this remains an important public health problem more than four decades after enforceable dust limits were implemented, and suggest that for miners in certain portions of the industry, the burden of debilitating respiratory disease is currently higher than national and regional levels from 10, 20 or even 30 years ago. If implemented effectively, the protections outlined in MSHA’s rule to lower miners’ exposure to respirable dust represent historic and welcome progress in the effort to safeguard the health of US coal miners.

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Competing interests None.

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