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A Critical Review of Coal Workers Pneumoconiosis (CWP) and Coal Rank for Evaluation of Safe Exposure Levels in Coal Mining

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Abstract

The US coal mine dust ("CMD") standard is among the lowest in the world. Lowering exposures to <2 milligrams per cubic meter ("mg/m^3") markedly reduced prevalence of coal workers pneumoconiosis ("CWP"). Lowering the standard to 1 mg/m^3 is proposed because of a recent increase in rapidly progressive coal workers pneumoconiosis. The question addressed in this review is whether coal rank should be considered in setting a new standard. In 1949 the first British coal dust standard for anthracite was 650 particles/cm^3 compared to 850 particles/cm^3 for lower ranked coals. The TLV for anthracite is 0.4 mg/m^3.

Exposure-response analyses of CMD and category ≥2 CWP show strong associations for high rank coal (coal rank 5 or anthracite and rank 4) with increased prevalence below the current standard. There were no apparent increases in CWP ≥2 for low rank coals 1-3 at exposures below the current 2.0 mg/m^3 standard. All studies show higher prevalence of CWP at higher ranks compared to lower ranks without regard to dust concentration. Assuming a background prevalence of 5% among non-dust exposed workers, the evidence suggests that below 2.0 mg/m^3 there is no excess CWP ≥2 for coal ranks 3-5 (low-medium ranks) in the US.

Exposure-response of CMD and mortality shows a strong association with nonmalignant respiratory diseases ("NMRD"), but no associations with chronic bronchitis, emphysema, lung cancer or stomach cancer. When stratified by rank, the excess NMRD mortality is confined entirely to miners exposed to anthracite.

This review confirms the important role of rank in development of CWP and indicates a substantial increased pulmonary fibrogenicity when exposed to high vs. low rank coals. These data are suggestive that the current standard may not be protective for the highest rank coals. Recent evidence suggests further exposure-response analyses are needed using more specific exposure metrics including iron.

Keywords: Bias; Bioavailable iron (BAI); Coal mine dust (CMD); Coal rank; Coal workers pneumoconiosis (CWP); Exposure-response; Radiographic category

Abbreviations: BAI: Bioavailable iron; CMD: Coal mine dust; CWP: coal workers pneumoconiosis; ILO: International Labour Office; MSHA: Mine Safety and Health Administration; NBC: British National Coal Board; NIOSH: National Institute of Occupational Safety and Health; NSCWP: National Study of Coal Workers' Pneumoconiosis; NMRD: Nonmalignant Malignant Respiratory Disease; PMF: Progressive Massive Fibrosis; REL: Recommended Exposure Limit; SMR: Standardized Mortality Ratio

Introduction

In the US the MSHA has proposed to lower the respirable CMD standard to 1.0 mg/m^3, which would be the lowest exposure standard in the world. Standards in other countries include Finland and the Netherlands at 2 mg/m^3; Australia, Italy and the UK at 3, 3.3 and 3.8 mg/m^3; and Yugoslavia at 4 mg/m^3.

Major potential confounding risk factors for CWP include quartz exposure and coal rank. High quartz exposure in the Southern Appalachian Region (SAR) of the US has produced rapidly progressive CWP that appears to be silicosis [1]. In the US at least this increased quartz exposure is related to fewer mines with small mine employment, and increased mining of low coal seams surrounded by high silica-containing rock producing coal with large quantities of quartz (e.g., 30-40%).

Coal rank[1] is an important risk factor for CWP as exposure-response and toxicity are related to rank. Low rank coal dust contains a lower proportion of uncoated silica[2] particles than dusts of high rank coal [2], so part of the toxicity may be related to quartz. Freshly crushed high rank coal contains a greater concentration of oxygen radicals [3,4] and smaller particle sizes [5] than lower rank coals.

"Black lung" was recognized as a disease in British coal miners in the mid-17th century and called a pneumoconiosis ("dusty lung") in 1874. Silica was thought to be causative agent until CWP was found to occur when there was minimal silica in the CMD. CWP is detected via chest radiographs with severity measured by profusion of opacities. Stages of CWP are defined by the International Labor Office ("ILO") Guidelines for the Classification of Radiographs of Pneumoconioses and divided into major categories of normal (category 0) simple CWP

[1]Coal rank defines the carbon content with higher ranks having more carbon (and lower rank number). Coal ranks go from 100 to 900 in the UK and 1 to 5 in the US. Number 1 is the highest ranking coal, anthracite with 93-95% carbon, and number 5 is the lowest ranked high volatile Western coal with <85% carbon.

[2]In this paper the term "silica" refers to the crystalline silica polymorph of quartz.

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(categories 1, 2, 3) and progressive massive fibrosis ("PMF") where opacities are ≥ 1 cm diameter (categories A, B, C). Major categories of simple CWP (small opacities) are subdivided into three subcategories (e.g. Category 1 is divided into 1/0, 1/1 and1/2). Category 2 CWP is the health condition of concern as the likelihood of a miner progressing in severity and contracting the more disabling and sometimes fatal condition of PMF is dramatically reduced or eliminated if ILO Category CWP 2 is never reached.

Rank of coal is a classification based on fixed carbon, volatile matter, and heating value of the coal. Coal rank indicates the progressive geological alteration (coalification) from lignite to anthracite. The term 'rank' refers to the quality of the coal. High rank coal has higher carbon content and is relatively smokeless. It includes anthracite, steam coal and high-grade coking coal. Low-rank coal has lower carbon content such as smoke-producing house coal. The British National Coal Board ("NCB") uses nine major ranks of coal (Table 1).

Coal rank has historically been understood to be related to the incidence and prevalence of CWP. A 1942 study in 16 collieries in South Wales found the highest prevalence of radiological abnormalities in anthracite mines and the lowest in bituminous mines with steam-coal mines intermediate. Using three broad rank categories (100-400; 500-600; and 700-900) a study in the UK found it took eight years to produce a 20% prevalence of CWP when exposed to highest rank, 16 years for the intermediate ranks, and 36 years for the lowest ranks [6]. In 1949 the first British coal dust standard for anthracite was 650 particles/cm^3 compared to 850 particles/cm^3 for lower ranked coals.

We will summarize and comment on individual studies that provide current data on the potentially confounding effect of coal rank on risk of developing CWP.

Comments on Studies of Exposure-Response Studies of CWP by Coal Rank [7]

This paper is a summary of results from other studies that have investigated characteristics of CMD that could produce different exposure-response associations. Results indicate:

- Degree of surface coating of coal in part determines the biological availability of silica, with the greater the occlusion the less the biological availability [8];
- Fresh-fractured coal and rock on the surface of high rank coal is more reactive *in vivo* than aged silica;
- Higher ranked coal produces a higher electromagnetic charge on breaking;
- Coal fractions are positively correlated with moisture and negatively correlated with electrostatic field. The largest amount of respirable particles are produced from lower rank coals;

Rank	Description	Approximate Carbon content
100	Anthracite	95-93%
200	Low volatile steam coal	93-91.5%
300	Prime coking coal	90.5-89
400	"	89-87
500	Coking /gas coal	87-85
600		85-84.5
700	General purpose coal	84.5-83.5
800	High Volatile steam	83.5-81.5
900	and house coal	81.5-80

Table 1: The British National Coal Board ("NCB") nine major ranks of coal.

- The higher the electrostatic charge the greater the lung deposition [9];
- Freshly broken coal and quartz contain highly reactive free radicals (electric charges) and potentially greater cytotoxic effects.

The authors conclude "charging" characteristics of coal suggest a significant cause-and-effect relationship between the coal rank-related charging characteristics, enhanced respiratory deposition and toxicity of airborne respirable particles, and the increased incidence of CWP in high rank coal regions.

Critique of Page and Organiscat (2000) [7]

This article provides support and possible reasons for increased prevalence of CWP in higher ranked coals. The evidence is reasonable but indirect in that it is largely lab-generated and not measured in the field. It is clearly reasonable that the amount of occlusion determines (i.e. at least partially) the amount of biologically available silica in an inverse relationship. A second factor relates to free radicals found on freshly fractured rock and coal from high rank coal areas. There is a consistent positive correlation with the amount of respirable sized particles related to increased coal rank. The authors' discussion relates to both quartz and coal rank. Nonetheless, they reason that the amount of airborne respirable dust produced from different coals can be predicted based on coal rank parameters. Moreover, the authors call for more effective dust generation and abatement (for higher rank coals) through engineering control technology.

Comments on studies of exposure-response studies of CWP by coal rank [6]

This paper studies the relationship between rank of coal mined and the prevalence of CWP among all face-workers in the UK during the 3rd survey of the NCB's periodic x-ray surveillance program. There were 250 collieries and 62,362 face workers with at least five years tenure, the earlier job being at the face. Prevalence rates were the percentage of radiographs showing category ≥1/0 collected at each colliery 1969-73.

The authors note that the quartz content of airborne dust is higher when low-rank coal is mined than when high-rank coal is mined. From the paper, it is not clear whether this quartz is admixed in the coal or is from rock surrounding the coal seam. High rank coals have a low number and include anthracite, low volatile steam coal and high-grade coking coal (starting at rank 100). Low rank (high number) coal is bituminous and smoke-producing house coal (ranks coming down from 900).

Coal rank of each colliery in this study was based on one of the following criteria: (a) all coal of one rank; (b) if two ranks are mined the one with highest tonnage was selected; (c) if three ranks are being mined the ranking is based on the rank with tonnage greater than the other two, or the central rank if output is similar; (d) when coal is limited to three or four adjacent ranks the extreme rank is selected if represented by at least ¾ of output.

Mean colliery exposure was gravimetric (mg/m^3) measurements collected at the face from 1970-1976, so prevalence of CWP is based on exposures experienced around the time the relevant X-rays were taken, but exposures causing the CWP were during an earlier period before gravimetric sampling was introduced.

The authors conclude that for coal ranks 200-900 there is a progressive fall in CWP prevalence with decreasing coal rank that cannot be ascribed to a rising gradient of mean age nor to dust concentrations with lower exposures occurring at the higher ranks of coal.

Critique of Bennett et al. [6]

Figure 1 displays the exposure-response trend of CWP ≥1/0 prevalence by mean exposure and coal rank. These data suggest two significant results are related to coal rank. Miners working in higher ranked coals (100-400, with rank 200 being an exception) tend to have a higher prevalence of CWP (13-21%) but lower dust exposures (3.1-5.0 mg/m^3). Miners working in lower ranked coals (500-900) tend to have a lower prevalence of CWP (3.9-11%) but higher CMD exposures (5.1-5.5 mg/m^3). The higher prevalence of CWP in some bituminous coal mines might be related to the higher quartz content in airborne dust in lower-rank coals than higher ranked coals. Whether this is because there is more quartz admixed in the low-ranked coal deposits, or whether it is necessary to cut into more of the strata above and below the low rank coal seam encountering more quartz in waste rock, is unclear.

There is an apparent downward trend in CWP prevalence with increasing mean exposure except for the outliers of low-ranked coals 300 and 200 where prevalences are highest and exposures are at the low end of the high-ranked coals (Figure 1).

Note that the average exposures among face-workers in this study are well above the US standard of 2.0 mg/m^3; most exposures were above 5.0 mg/m^3. These mean gravimetric exposure estimates in mg/m^3 are quite high. Unfortunately, earlier non-gravimetric sample results prior to 1970 are not evaluated. The absence of these data is a limitation that produces over-estimates of the toxicity of CMD if concentrations at the face were higher before 1970.

The exposure-response trends are further limited as the pre-1970 period is when CWP would be developing in these miners. The exposure estimates are based on the average of all mines, so exposure is an ecological (group-based) estimate rather than a preferred estimate based on individual exposures over an entire work-life in coal mining.

There is a "well-marked" relationship between CWP category ≥1 and coal ranks 200- 900, with prevalence falling from a high of 20.8% at rank 200 to a low of 3.9% at rank 900 (Figure 2). Prevalence in coal rank 100 (Anthracite) is midway between ranks 300 and 400. This difference is apparently not due to a difference in mean age (anthracite miners' age was 47.1 years compared to 44.5 and 44 years for ranks 200 and 300).

Difference in average exposure could be a factor as it was lowest (3.1 mg/m^3) for anthracite miners while lower ranks ranged from 3.9 for rank 400 to 5.5 mg/m^3 for rank 900, or 5.0 and 4.8 mg/m^3 for ranks 200 and 300 respectively) (Figure 2). However these exposure estimates are for recent exposures and may not correlate well with exposures existent when the radiological abnormality was developing. This study provides an estimate of intensity (mg/m^3) only at the time the response (CWP) is being measured, without consideration for the entire work history and earlier exposures to coal mine dust. As a result data from this study should not be considered reliable for determining exposure-response trends between CWP and exposure to CMD.

Figure 2 also shows a tendency for prevalence to be somewhat similar within the same rank of coal, although the 3 to 5-fold differences in prevalence within the same rank suggests factors other than rank are of importance in determining prevalence of CWP.

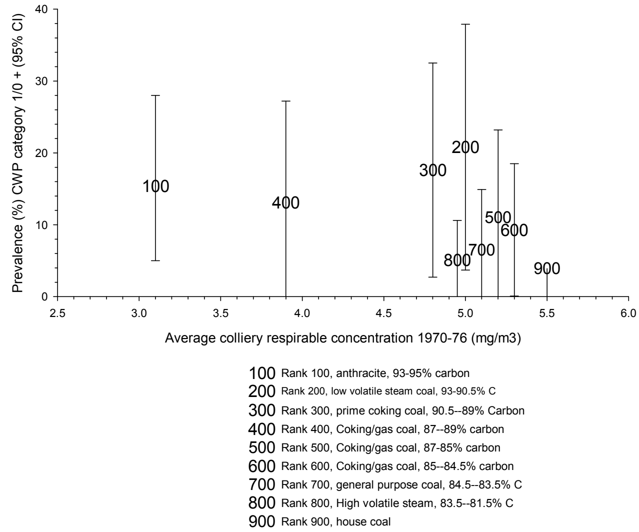

Figure 1: Relationships between coal rank, pneumoconiosis equal to or greater than category 1/0 and mean colliery respirable dust concentration 1970-76 among 247 colleries in UK National Coal Board's Periodic X-ray Scheme Bennet et al, 1979.

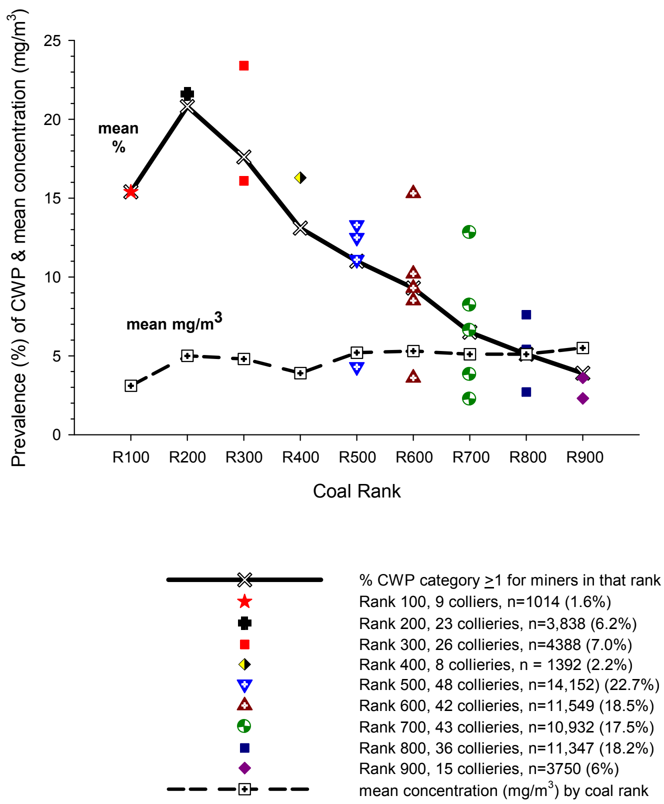

Figure 2: Prevalence (%) of CWP 1+ and mean concentration (mg/m^3) in face workers by coal rank in 9 areas and 250 collieries in Scotland (Bennett et al, 1979).

These data are somewhat consistent with other findings suggesting the prevalence of CWP ≥1 is higher among high rank coals than lower rank coals. The data are seemingly inconsistent for the highest rank

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of coal as prevalence is somewhat intermediate for anthracite. Other factors, especially an individual exposure-response analysis, are important for more definitive conclusions regarding other risk factors affecting prevalence of CWP.

Comments on studies of exposure-response studies of CWP by coal rank [10]

This is the first exposure-response study of US coal miners using quantitative estimates of exposure (gh/m^3) instead of tenure or job. The present exposure limit of 2.0 mg/m^3 is largely based on results from studies of British miners. The prime objective of this study was to develop exposure-response relationships between CWP and CMD in US coal mines.

The cohort consisted of miners from 31 underground US mines examined in 1969-1971 as part of the first round of the National Institute for Occupational Safety and Health ("NIOSH") National Study of Coal Workers' Pneumoconiosis ("NSCWP"). The relevant parts of the examination for this study included chest radiograph, spirometry, work and smoking histories.

Three data sets were utilized to estimate cumulative CMD exposures that occurred prior to the miners' examinations; viz. the work histories from the miners in the NSCWP 1969-1971, MSHA compliance data 1970-1972, and BOM data 1968-1969. The BOM data were collected at 17 of the mines included in this study and are the only body of gravimetric data prior to 1970 that were available for this study. Exposure estimates used in exposure-response analyses were based on 1970-72 compliance samples and back extrapolated to pre-1970 miner work experience by using an average factor derived from the ratio of job specific BOM/MSHA data and then applying this factor to the MSHA compliance data in 1970-1972.

Each coal mine was classified into one of five rank categories.

1. Rank 1 coal was anthracite from 2 mines in eastern Pennsylvania with 521 miners (5.8% of total observations). Estimated dust concentration was 3.2 (0.7) mg/m^3.
2. Rank 2 coal was Medium/low volatile bituminous (89-90% carbon) coal from 6 mines in central Pennsylvania, and southeastern West Virginia with 1362 miners (15.1% if total observations). Estimated concentration was 3.1 (1.0) mg/m^3.
3. Rank 3 was High volatile "A" bituminous coal (80-87% carbon) from 16 mines in western Pennsylvania, West Virginia, eastern Ohio, eastern Kentucky, western Virginia and Alabama. This is the largest group with 4934 miners or 54.7% of the total observations. Estimated dust concentration was 3.0(0.9) mg/m^3.
4. Rank 4 was High volatile Midwestern coal from 4 mines in western Kentucky and Illinois with 1225 miners (13.6% of total observations). Estimated dust concentration was 3.0(1.0) mg/m^3.
5. Rank 5 was High volatile West coal from 3 mines in Utah and Colorado with 981 miners (10.7% of total observations). Estimated dust concentration was 2.8 (1.1) mg/m^3.

There are clear, strong associations of prevalences of CWP ≥2 and exposure to high rank coals 1 and 2 while associations with coal ranks 3, 4 and 5 are weaker with excesses occurring only at higher exposures (Figure 3). Prevalence of PMF is lower with strong exposure-response trends for Ranks 1 and 2, and prevalence generally below 5% for ranks 3-5 (Figure 4).

Age is significantly associated with development of CWP and thus a potential confounder. Exposure-response analyses using logistic regressions adjusting for age produced comparable strong associations of CWP category ≥2 with coal ranks 1 and 2. There was no association with coal rank 5 with either category ≥2+ or PMF (p = 0.82 and 0.92

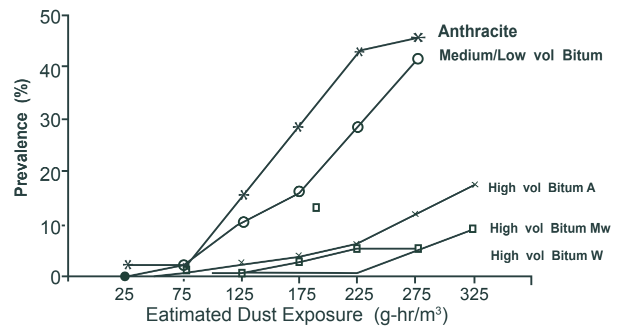

Figure 3:

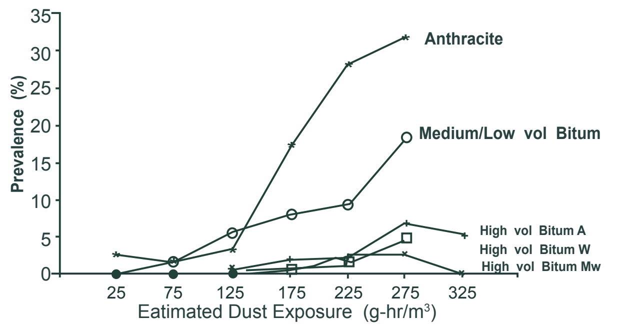

Figure 4:

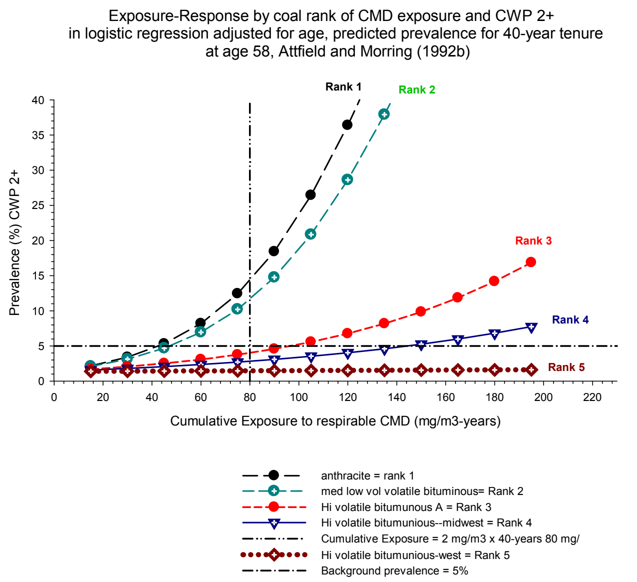

Figure 5:

respectively). Category ≥2 and PMF were significantly associated with coal ranks 1-4, except the association of coal rank 4 and PMF were not significant (p = 0.48). Prevalence of Category ≥2 was at or below 5% (close to background levels) when cumulative exposure was below 70-90 mg/m^3-years (Figure 5).

Critique of Attfield and Morring [10]

The authors' note a limitation of this study in that there was only one reader of chest films, although the similarity with readings from the UK provided some comfort that it should not lead to major errors in prevalence or exposure-response relationships.

CWP ≥2 is more reliable than CWP ≥1 and should be the response-variable used to establish exposure-response trends because profusion of small opacities in CWP1 can be from other causes (e.g. smoking and lung conditions). Classification of CWP ≥2 is a relatively clear and reliable indicator of CWP when coupled with CMD exposures.

Figures 3 and 4 [10] show similar trends for category ≥2 and PMF using the British cumulative exposure metric of g/m^3-hours. Transformation to the cumulative exposure metric of mg/m^3-years and use of logistic regression results in the exposure-response trend for category ≥2 CWP shown in Figure 5.

The background level of CWP is estimated to be about 5% [11]. At this background level there is excess CWP ≥2 at around 40 mg/m^3-years for high ranking coals 4 and 5. For lower ranking coal there is no apparent excess CWP ≥2 below the standard of 80 mg/m^3-years (2 mg/m^3 x 40 years) or 70 mg/m^3-years (2 mg/m^3 x 35 years). The apparent thresholds are about 100 and 140 mg/m^3-years for coal ranks 3 and 4. Coal rank 5 showed no associations with excess CWP ≥2 as the exposure-curve was flat (Figure 5). Results shown in Figure 5 are the most important in this study because of the adjustment for potentially confounding effect of age. It would have been useful to confirm whether smoking was a confounding non-occupational risk factor.

Figure 6 shows the predicted effect of coal rank on prevalence of different categories of CWP. These data are derived from statistical models predicting prevalence based on the effects of a 40-year work life at 2 mg/m^3. There appears to be no excess prevalence of categories CWP 1 and CWP 2 for ranks 3-5 when background levels of abnormal radiographs are taken into account. The predictions are also based on exposures prior to 1970, a time when concentrations could be as high as 8 mg/m^3.

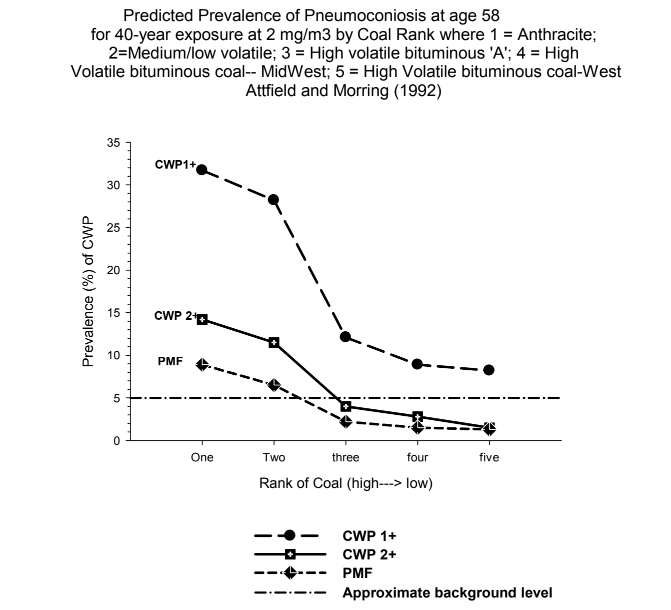

Figure 6:

A major limitation of this (and other US studies) is that exposure is based on sample results taken about the time the 3.0 mg/m^3 standard was initiated. The period before about 1970 was a period of high exposures with 21 of 25 jobs above the current standard and ranging as high as 8.4 mg/m^3 [12]

The data in this report provide strong evidence that rank of coal is an important factor to be considered and seems implicated in the etiology of CWP. When working in coal ranks 1 and 2 excess prevalence of CWP ≥2 prevalence may occur at exposures below the current CMD standard. There were no apparent excesses at lower coal ranks 3-5, and coal rank 5 is similar to a nuisance dust with a flat exposure-response trend.

An important limitation of these data is the biased estimate of exposure. Exposures are over-estimated when job concentrations are below 4mg/m^3, and exposure is under-estimated when job concentrations are greater than 4 mg/m^3. The overall effect of the biased estimates of cumulative exposures is to produce spuriously stronger exposure-response trends that suggest excess prevalence occurs at lower estimated concentrations than would occur if exposure estimates were unbiased. This limitation is important in consideration of safe exposure levels, and is discussed at length where this topic is specifically addressed [13]. While this exposure misclassification bias significantly affects exposure-response associations it should have negligible effect on consideration of coal rank because the bias should be similar for all ranks of coal.

It is unusual in the US to estimate cumulative exposure using the g/m^3-yhours employed in the UK. Attfield and Morring assumed a working year of 1740 hours/year (217.5 days/year at 8-hours/day) from British data because of the lack of US data. Tenure for this cohort is in years. Given the uncertainty in the actual number of hours worked in US mines "owing to the effect of strikes and layoffs, which have periodically affected the [US coal] industry," it seems preferable to have used the more commonly used mg/m^3-years metric. The authors indicate it has no effect on the prediction models; and should have no effect on assessment of rank. The actual hours or days worked will have an effect on the exposure-response association that is of unknown magnitude or direction.

Comments on studies of exposure-response studies of CWP by coal rank [11]

This is a cohort study of US underground miners and ex-miners. There were three broad categories of coal rank. The high coal rank category of miners were from Pennsylvania and southwestern West Virginia (about 2000 miners); the low rank group was from Kentucky, Illinois, Colorado and Utah (about 2200 miners); the medium rank comprised all the other states including Ohio (350), Tennessee (100), and Virginia (600).

The entire cohort comprised 7,281 miners who participated in Rounds 1 and 2 of the NSCWP begun in 1970. There were 3,194 (44%) participants selected for study who were <59 years old in 1985 and were examined in Round 4. Miners excluded from the study were from areas where it was not feasible to conduct further surveys.

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Cumulative exposure ranged from 0 to 211 mg/m^3-years with a mean of 34 mg/m^3-years. Most (75%) of the cohort had low exposures between 13-41 mg/m^3-years.

The overall prevalence of CWP ≥1 (all major categories) was 4% (n = 131); 0.7% (n=23) for CWP ≥2 (categories 2, 3) and 0.8% (n= 28) for PMF. Exposure-response trends for prevalence of CWP ≥1 were similar for all three ranks but became steeper at about 70 mg/m^3-years for high rank > low rank > medium rank coal.

Age, cumulative dust exposure and effects of exposure to high rank coal dust were significant factors affecting prevalence of CWP ≥1, CWP ≥2 and PMF. There were clear exposure-response trends of increasing CWP with increasing cumulative coal dust exposure. The exposure-response slope became even steeper from the added effect of exposure to high rank coal dust (Figure 7).

Predicted prevalence of CWP at high- and low-ranked coal from this study, from the first round of the US coal mine survey [10] and from British coal miners [14] show a clear exposure-response trend for CWP prevalence to be higher in hard coal than in soft coal. These data calculated from statistical models for miners after 40 years exposure at 2.0 mg/m^3 are summarized in Figure 8.

Critique of Attfield and Seixas [11]

These data show clear exposure-response trends for CWP to increase with increasing cumulative exposure. The trends of CWP ≥1 and CWP ≥2 are essentially the same. When the effects of high ranked coal are added, the slopes are increased substantially showing high rank coal produces more CWP than low rank at the same mass exposures.

There are several issues relating to evaluating associations of CWP and CMD exposure relating to exposure-response and the proposed CMD standard. One of these is the issue of coal rank, which is the subject of this review. Others include: misclassification of exposure and resulting biases; background prevalence of radiographic findings that mimic CWP in non-exposed workers; and potential biases from low participation. These issues will be discussed in a separate paper reviewing the exposure-response trends for use in deriving safe exposure levels [13]. Biases are unlikely to be correlated with coal rank, in which case they are not confounding the association between CWP and rank of coal mine dust. We assume potential bias from participation rates and pre-1970 exposure estimates are similar by region and coal rank. If so, results regarding effects of coal rank should not be biased.

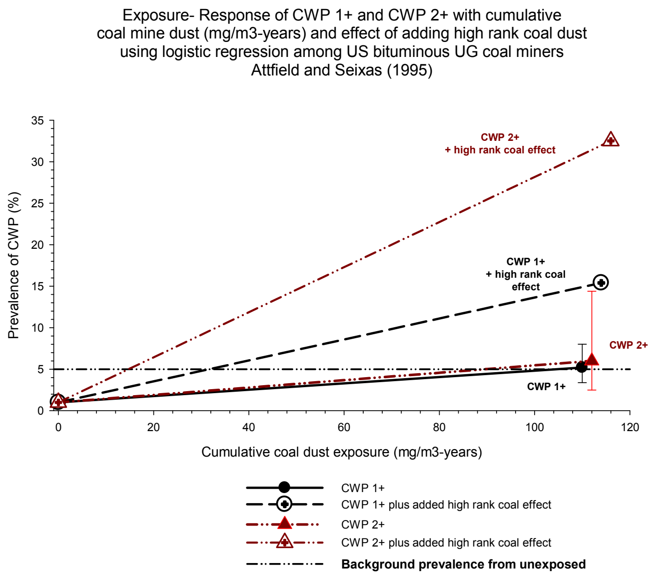

Figure 7:

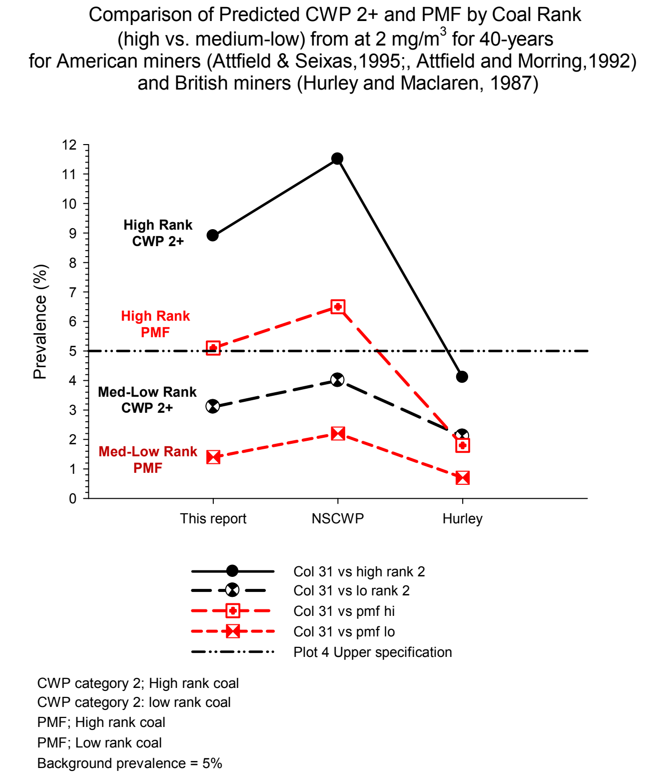

Figure 8:

The authors suggest there is reasonable consistency of findings from three different studies. The graphic display of these data in Figure 9 do not completely support this interpretation as the prevalence of CWP ≥2 and PMF are consistently lower in the UK than the US.

In sum, these data indicate the prevalence of CWP is clearly elevated above background levels at exposures below the current standard. Coal ranks 3 and 4 show increased CWP ≥2 after long and high exposure above the standard, while the lowest coal rank 5 shows no apparent association with CWP ≥2 at even the highest exposure levels.

Comments on studies of exposure-response studies of CWP by coal rank [15]

This mortality study is the same cohort of 9,078 miners in 31 coal mines followed for nine-years until 1979 by Kuempel et al. [16]. The new study is essentially the same data and analysis but with 22-24 years follow-up of vital status until the end of 1993, which increased the number of deaths from 793 to 3,213 thereby increasing the power of the study. The total cohort was reduced to 8,899 because of 1.5% with missing data, 0.52% lost to follow-up or no death certificate located. Working miners >65 years of age were not excluded. There were no updates on smoking or work history, so any changes after 1969-71 were not recorded.

SMRs for NMRD and Pneumoconiosis (and other respiratory

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diseases) show a clear trend of increasing mortality with increasing exposure. Categories 1, 2, 3 and PMF are a result of exposures prior to 1970, so exposure estimates are biased. All of the radiological categories were due to exposures before 1970, since the radiographic data on each individual were collected 1969-71 and only vital status was updated. Work histories, and therefore exposure as well, are unknown beyond 1970 so a maximum of 22 years of exposure are potentially excluded. Thus some portion of all cohorts' work history and exposure are underestimated.

Risks of NMRD were also evaluated by four coal ranks in the proportional hazards model from high rank to low rank: anthracite (rank 1), East Appalachia (rank 2), West Appalachia (rank 3), and Mid-West (rank 4). These data show that the risk of NMRD is from the four-fold increased risk of anthracite, and no increased risk is associated with the lower ranks of coal (Figure 9).

Critique of Attfield and Kuempel [15]

The most interesting finding shown in Figure 9 is that excess mortality from NMRD, and presumably CWP as well, occur only when mining high rank coal. In so far as NMRD reflects CWP mortality, these results are consistent with morbidity results based on radiographic findings rather than cause of death.

Comments on studies of exposure-response studies of CWP by coal rank [18,19]

McCunney et al. [17] reviewed the literature focusing on the risk of CWP from active agent(s) within coal so that by understanding these risks improved preventive actions could be instituted.

CWP was originally thought to be a variant of silicosis. Quartz exposure may be related to development of CWP, but silicosis is a distinct disease with different characteristics and a separate standard. CWP is related to CMD exposure but not to quartz exposure. They note the long recognized link between decreasing rank of coal and increasing prevalence of CWP, and the usefulness of US data because of the wide range of coal types and ranks of coal. Several reasons in addition to those of Page and Organiscat [7] were cited that are consistent with a strong association between coal rank and CWP prevalence in included the following:

* Hemolysis from *in vitro* exposure to high rank coal [20].
* Decreased clearance and increased retention time of anthracite coal compared to lower ranked coal among chronically exposed rats [21].
* More surface free radicals in higher ranked coals *per se* [22]and observed on autopsy of anthracite coal miner lungs compared to lungs of coal miners exposed to lower ranked coal [4].
* Larger surface area of higher ranked coal potentially causing greater lung irritation [23].

McCunney et al. [17] noted inverse associations of quartz and CWP, but positive associations with iron from two studies. Huang et al [18] showed that variants of iron (e.g., BAI or bioavailable iron, total iron, pyritic sulfur) showed more consistent associations with prevalence of total CWP than quartz, and a higher correlation than with bituminous coal rank using molar ratio (C:H ratio) as the coal rank metric. In seven US bituminous coal mining regions there were high correlations between total prevalence of CWP and various metrics of iron: r =0.94 (0.66-0.999) for BIA; r = 0.91 (0.35-0.99) for pyritic sulfur; and r = 0.85 (0.20-0.97) for total iron. The correlation of total CWP and coal rank measured as C:H ratio was 0.59 (-0.26-0.91) [18].

This evidence led Huang et al [18] to the conclusion that iron (or more specifically BIA in bituminous coal) is the likely active agent causing CWP. This iron hypothesis is consistent with *in vitro* studies showing a possible mechanism. The iron pyrite (FeS_2) component in coal was reported to spontaneously form reactive oxygen species (ROS) (hydrogen peroxide and hydroxyl radicals) that produce inflammation and degrade RNA. And FeS_2 was correlated with prevalence of CWP [19].

Critiques of McCunney et al. [17], Huang et al. [18, 19] and Cohn et al. [19]

We thank a reviewer of a draft version of this report for drawing our attention to the important issues raised in these articles.

McCunney et al. [17] is an important review that indicates the important role of exposure-response of CMD and CWP in establishing causality, while refuting the traditional but inconsistent association of quartz with prevalence of CWP. The inconsistent associations with quartz in coal were in part related to bioavailability or surface reactivity of the quartz and its context in the mineral body. These factors are not considered in our earlier review where we focused on the lack of consideration of high quartz levels in the proposed MSHA CMD levels.

The mechanisms for development and progression of CWP are in part based on strong correlations of BIA with cross-sectional prevalence of total CWP [18]. This epidemiological evidence is consistent with *in vitro* formation of reactive oxygen species associated with iron content (as pyrite) in the coal. The ROS were considered to be the proximate cause of RNA degradation and CWP [19].

Coal rank (at least the highest rank of anthracite) remains a significant metric for estimating risk of CWP. Anthracite coal has greatest potency producing CWP relative to bituminous coal, but further analysis is required because it was not included in the analyses of iron [18]. It is not clear why anthracite was excluded, perhaps for lack of data on iron content. In contrast, a relatively complete database of carbon: hydrogen content of coal is a strength of the coal rank metric. The consistency of the data provides strong support for the iron

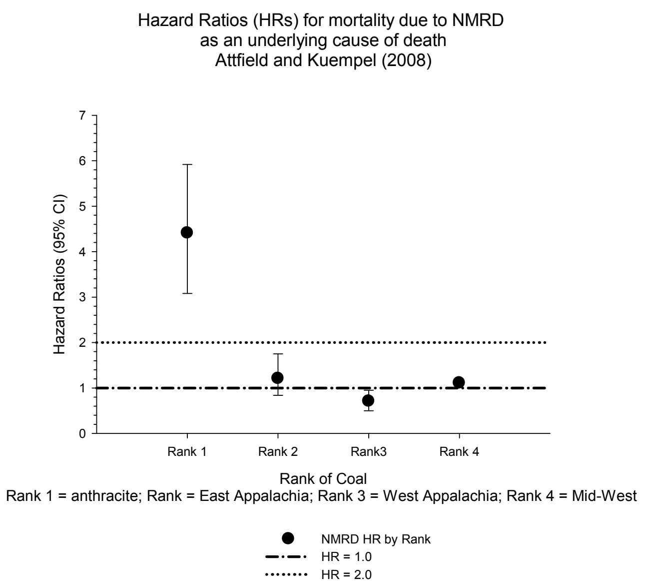

Figure 9:

Citation: Gamble JF, Reger RB, Glenn RE (2012) A Critical Review of Coal Workers Pneumoconiosis (CWP) and Coal Rank for Evaluation of Safe Exposure Levels in Coal Mining. J Clinic Toxicol S1:009. doi:10.4172/2161-0495.S1-009

hypothesis with regard to bituminous coals, although Huang et al [18] do not conclude a causal association is certain. Limitations include the following:

* Not all coal types were studied and additional analyses are needed that include all coal types.

* Anthracite coal was excluded, so the highest rank and most potent coal was not studied. * Some mines in the first round of NSCWP, western coal mines and some surface mines where CWP is low were not included in the assessment of BAI.

* The epidemiological correlation analysis needs to be improved. The reported analyses were based on correlations of CWP prevalence in the 29 bituminous mines from the first round of the NSCWP [25] with physicochemical data from the US Geological Survey Database. These correlation analyses need to be replaced with individual exposure-response analyses already conducted in US coal miner cohorts [10,11]. The new and improved exposure-response analyses should be multivariate, transforming the cumulative exposure to respirable CMD to the possibly more accurate effectors of BIA, FeS_2, or total iron. Interactions with coal rank (as a categorical and molar ratio metric) should be explored statistically to determine the best-fitting models. These analyses will provide significant data on several issues:

* Definitive tests of the iron hypothesis by inclusion of all coal ranks and direct comparisons will determine the relative importance of the available exposure variables.

* If iron is the more accurate risk factor for induction of CWP, the associations will be stronger and will improve the precision of threshold effects.

* Analyses for iron may be added to the gravimetric analysis of respirable CMD currently used for estimating CMD exposure.

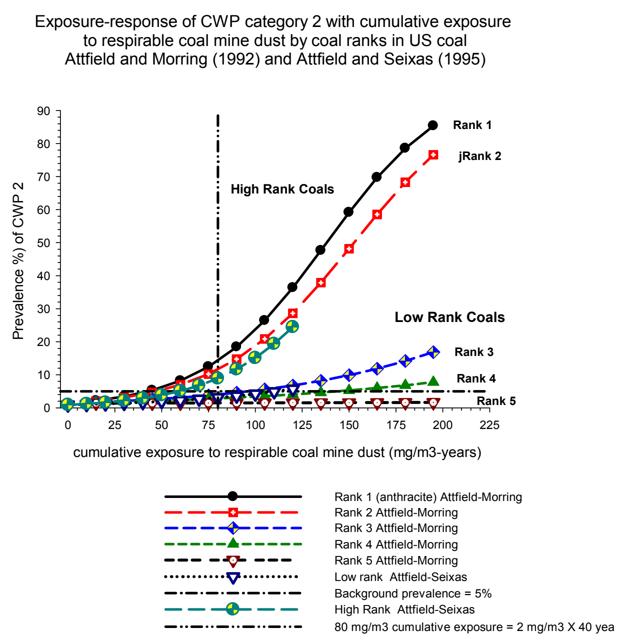

Figure 10:

* Confirmation of the iron hypothesis will provide a more direct estimate of CWP risk and greater precision in estimating potential risk of un-mined coal fields.

- Other factors were not considered, including particle size, other bioavailable transition metals, effects of phagolysosomes of cells contributing to acid solubilization. However, these factors are limitations as relevant to the metric of coal rank as they are to BIA.

- Further *in vitro* and *in vivo* studies of role of BIA in cell and lung injury are needed.

The iron data provide a plausible and potentially more relevant metric for assessing exposure-response links between CMD and CWP. This evidence appears to be internally consistent, but more definitive tests are required. Correlations are suggestive, but further concurrent analyses of respirable CMD, iron in the respirable CMD samples are needed. And these more definitive individual exposure-response analyses appear to be feasible as they can be based on existing data. It appears to be a conceptually simple transformation such as (for example) mass respirable CMD to mass BAI and coal rank to molar ratio.

Summary

Recent studies confirm the important role of coal rank in development of CWP and show a substantially higher pulmonary fibrogenicity of high vs. low rank coals. The higher the rank of coal, the greater the prevalence of all categories of CWP. These associations were observed in all the studies from both the UK and the US without exception.

The British study presented radiological CWP category ≥1 by coal rank without an exposure-response analysis [6]. The American study of mortality presented SMRs for NMRD by coal rank in a similar manner [15]. The US morbidity studies by CWP category ≥2 and PMF conducted exposure-response analyses and statistically analyzing the effects of coal rank and age [10,11]. The exposure-response results of both the American studies are shown together in Figure 10, and comprise the primary data regarding the role of coal rank and prevalence of CWP.

All studies show higher prevalence of CWP at higher ranks compared to lower ranks without regard to dust concentration. Assuming a background prevalence of 5% among non-dust exposed workers, the evidence suggests that below 2.0 mg/m^3 there is no excess CWP ≥2 for coal ranks 3-5 (low-medium ranks) in the US (Figure 10). These data are suggestive that the current standard is adequate for low ranking coal, but the standard for the highest rank coals may not be protective.

These data are the most complete and relevant to date for assessing the role of coal rank in determining risk factors for CWP. However, there are newer data suggesting coal rank and respirable CMD may be only partial or indirect exposure measures of more proximate causal risk factor(s), namely iron (e.g., mass of bioavailable iron, iron pyrite, or total iron). These exposure metrics and coal rank (perhaps as molar ratio) need to be evaluated in the existing exposure-response database.

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