Towards Understanding Coal Workers Pneumoconiosis

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History

The hazards of mining have been known since the 16th century, when early observers noted that Carpathian miners died from what was then known as “miners's phthisis”. It is now clear that this term had a generic connotation and included a large number of diseases, from pneumoconioses to lung cancer (Rom and Markowitz; 2007).

Background

Pneumoconioses are a group of lung diseases caused by inhalation and accumulation of inorganic or organic particles of mineral dust in the lungs. Respirable dust particles, up to 10µm in diameter, reach the alveoli where they irritate the lung tissue, causing inflammation and damage. Over time, macrophages phagocytise these particles and deposit them in the lung parenchyma in the form of coal maculae. In time, it can progress to form fibrosis and in severe cases, necrosis which can lead to pulmonary dysfunction and premature deaths (Murray et al; 2005).

Associated Diseases

Chest diseases which develop as a consequence of long-term exposure to coal mine dust include:

- **Restrictive lung diseases:**
  - Coal workers’ pneumoconiosis (CWP), silicosis, industrial bronchitis

- **Obstructive lung diseases:**
  - Emphysema, chronic bronchitis; collectively known as Chronic Obstructive Pulmonary Disease (COPD)(Rom and Markowitz; 2007).

Types of CWP

CWP one of the most widespread slowly progressive occupational diseases and is customarily divided into simple and complicated pneumoconiosis according to the severity of the lung scaring.
• **Simple CWP**, also known as “black-lung disease”, is best described as the deposition of fibrogenic mineral particles of coal mine dust in the lung parenchyma and the subsequent reaction to its presence; resulting in mechanical and architectural destruction of the lungs.

• **Complicated CWP**, known as Progressive Massive Fibrosis (PMF) occurs if an individual with simple CWP continues to be exposed to heavy dust concentrations. This form of CWP leads to the destruction of normal lung structures, potentially resulting in respiratory failure. (Weston; 2011)

Typically, chronic environmental or domestic exposure leads to disease after a variable number of years. Occurrence and rate of progression are related to the average cumulative mass of respirable dust to which miners are exposed during their career. (Attfi eld; 2013)

### Epidemiology

• As most jobs that carry high dust exposure are filled by male workers, the majority of deaths from CWP occur in men. (Wade; 2011)

• Pneumoconiosis usually develops over an extensive period of time, thus most cases occur in retired workers over 50 years of age.

• Approximately 6 out of 100,000 people suffer from a form of pneumoconiosis. (Wade; 2011)

• According to Yang and Liu (2012), the overall prevalence of pneumoconiosis in coal miners in United States was 11.2% in 1970-1974 and by 2005-2006 had decreased to 3.3% due to the Health and Safety Act introduced in 1974. The accepted level of occupational exposure to coal was established at 2mg/ m3 by the National Institute for Occupational Safety and Health.

• Surprisingly, from 1995 to 2006 the CWP rates have doubled in US. (Fig 3)
Pathophysiology of CWP

Simple Coal Workers Pneumoconiosis

CWP occurs when the body's natural mechanism for defending against and processing inhaled dust becomes overwhelmed and in consequence, over reactive. However, questions remain as to the active agent responsible for the occurrence and progression of CWP (Schins and Borms; 1999).

- The first point to be reached by the coal particles in the respiratory tract are the terminal bronchioles, where the carbon is engulfed by alveolar and interstitial macrophages. Macrophages are responsible for phagocytising coal particles and transporting them up the mucociliary elevator to be expelled in the mucus or through the interstitial lymphatic clearance route (Bowden; 1987).

- When the lungs are exposed to dust particles larger than 2-5 µm in diameter for a significant period, the dust-laden macrophages accumulate in the alveoli and an immune response may be triggered. Involved in this response are fibroblasts, which secrete reticulin and entrap the macrophages. The production of reticulin increases if the macrophages lyse due to the augmentation of the fibroblastic response (Lyons et al; 2009).

- If the inhaled coal dust contains silica, the macrophages lyse more rapidly and the stimulation of the fibroblasts adds more collagen to the lymphatic tree. When these macrophages migrate up the lymphatic vessels, the resultant interstitial fibrosis will cause the arterioles to become strangulated. As more macrophages die, more fibroblasts, reticulin and collagen are deposited along the vascular tree, compromising the vessels and ensuing ischemic necrosis (Bowden; 1987).

- Also known as coal macules, the pigment-laden macrophages and the areas of focal deposition of coal dust are the histologic hallmark of CWP.
Progressive Massive Fibrosis

As macules enlarge, nodules are formed and when these coalesce, PMF occurs. Tuberculosis or rheumatoid factor can exacerbate this process, as they accelerate the progression rate of focal ischemic necrosis and fibrosis. PMF reflects a more severe scaring and leads to respiratory insufficiency due to the growth of the fibrosis which causes obstructive changes to the airways (Yan and Lin; 2009).

Caplan Syndrome

Caplan syndrome results when PMF is associated with rheumatoid factor. The Caplan nodules exhibit a central area of coal dust and necrotic collagenous tissue lying in concentric rings and it is surrounded by an area of neutrophils with palisading fibroblasts (Rom and Markowitz; 2007).

Molecular mechanism of CWP

The inciting factors in the inflammatory process, which leads to tissue damage and fibrosis in CWP, are still not fully understood.

- The inhalation of coal dust causes a reaction which activates primary immune response genes such as cytokines, growth factors and tissue remodelling proteins (proteases and antiproteases) (Schins and Borms; 1999).
- Increased levels of Interleukin-1, 6 and 8 (IL-1/ 6/ 8), tumor necrosis factor alpha (TNF-), transforming growth factor beta1 (TGF-1), neutrophil adhesion factor Intercellular Adhesion Molecule-1 (ICAM-1), alpha1-proteinase inhibitor, fibronectin and monocyte chemotactic protein-1 (MCP-1) were observed in the bronchoalveolar lavage fluid of miners with CWP (Schins and Borms; 1999).
- MCP-1 (chemokine which attracts and activates monocytes) was also found to be responsible for further cell recruitment and secretion of lysosomal enzymes, factors that influence the progression of the disease (Boitelle et al; 1997).
- The antioxidants selenium and glutathione were found to be at lower concentrations in workers exposed to coal mine dust in comparison with healthy individuals. These findings suggest that the defence against reactive oxygen species (ROS) is weakened, a consumptive process which causes cellular damage and potentiates CWP and PMF.
- Huang et al (2005), determined the existence of a correlation between bioavailable iron (BAI), pyrite concentration, and the regional progression of lung disease. BAI is iron which mimics the interior of lysosomes as it dissolves in 10 mmol/l phosphate solution at pH 4.5. This study also demonstrated that iron, not quartz, is the active agent in coal responsible for CWP, as McCunney et al (2009) confirmed.
- These pyrite-induced ROSs are implicated in the inflammatory process and cellular...
damage, as they produce reactive agents shown to degrade yeast RNA, ribosomal RNA and DNA (Schins and Borms; 1999)

- Polymorphisms in the E-selectin gene (SELE), an adhesion molecule implicated in inflammatory processes, along with smoking, have been found to increase vulnerability to CWP.
- Also, a potential contribution of microRNAs (miRNAs) to CWP has been identified. Different stages of disease exhibited various relative expression levels of miRNAs, mostly showing a down-regulation trend. Therefore, these aberrantly and over-expressed miRNAs were determined to have a critical role in the occurrence and progression of CWP, with a great potential to become a non-invasive diagnosis biomarker (Guo et al; 2013)

Symptomatology

Individuals suffering from simple CWP usually display:
- Chronic cough and shortness of breath on exertion may be reported, however usually due to industrial bronchitis or smoking
- Mild loss of lung function

As CWP progresses to the more severe and complicated form, PMF, symptoms as follows may arisen:
- Tightness in the chest
- Dyspnea
- Chronic Cough with black sputum
- Pulmonary dysfunction (i.e. pulmonary hypertension)
- Right-sided heart failure due to lung dysfunction
- Cyanosis

Other constitutional symptoms such as fever and night sweats may occur if a superimposed mycobacterial infection is present (Petsonk; 2008)

Diagnosis and monitoring

If an individual presents any of the aforementioned symptoms, a series of diagnosis methods are to be employed:
- A full and detailed medical, occupational and environmental history
- Physical examination, with a focus on the chest area
- Use of pulmonary function tests (PFTs) (i.e Spirometry) in order to determine the severity of the impairment of lung function. Individuals suffering from simple CWP show no significant loss of lung capacity and function. However, the alveolar-arterial pressure gradient can show a minor decrease, while the diffusing capacity (P category – according to the ILO system to be described further) is slightly reduced. Also, secondary to physiological shunting, minimal hypoxemia can be observed. A slight increase in residual volume and in compliance of the lung can result if focal emphysema is present. In addition, pulmonary hypertension can occur if the size of the conglomerate mass is significantly large to destroy vascularity (Petsonk; 2008)
• **Measurement of arterial blood gases (ABGs)** can be used to determine impairments between oxygen and carbon dioxide in the alveoli (Petsonk; 2008)
• **CBC count** and a **sputum culture** can be performed, if needed, to eliminate the possibility of other infective processes (Petsonk; 2008)
• The **6-minute walk test (6MWT)**, a simple, additional test that can be performed as a mean of quantifying possible lung impairment due to CWP (Petsonk; 2008)
• **Imaging procedures**, such as chest X-rays and **Computed Tomography (CT)** scans, remain the primary diagnostic tools used to visualize the nodules and lung scarring and to evaluate the presence and progression of the disease. The radiographs obtained are to be compared against the standardized set of X-rays developed by the International Labor Organization (ILO) which reflects the amount of retained coal in the lungs. This 12 point classification scale represents a continuum of dust accumulation with nodule formation from category 0/0 to 3/4. (ILO; 2011)

### Table 1 – Overview of the ILO 2011 classification system

<table>
<thead>
<tr>
<th>Disease</th>
<th>Description</th>
<th>Classification</th>
<th>Lung zone</th>
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</thead>
<tbody>
<tr>
<td>Simple CWP</td>
<td>Small, rounded opacities</td>
<td>P - 1.5mm in diameter&lt;br&gt;Q – 1.5 to 3mm in diameter&lt;br&gt;R – 3 to 10 mm in diameter</td>
<td>Typically in the upper lobes</td>
</tr>
<tr>
<td>PMF</td>
<td>Nodular opacity is greater than 1 cm in diameter</td>
<td>A – 1.5 cm in diameter&lt;br&gt;B – 5 cm in diameter (occupying &lt; 1/3 of the lung)&lt;br&gt;C – 5 cm or more in diameter (occupying &gt; 1/3 of the lung)</td>
<td>Upper and middle zones of the lung lobes</td>
</tr>
</tbody>
</table>

(ILO; 2011)

Evaluation of chest X-rays is performed by trained physicians as B-readers in order to obtain a classification of the nodules or scars according to their size, shape and distribution in the lung.

• **Bronchoscopy** with a **lung biopsy**, an invasive technique that involves the removal of a small piece of lung tissue to be examined in the laboratory.

Of note, Reichert and Bensadoun (2009) conducted a small study which proved that positron emission tomography (PET) method is of limited value in the evaluation of CWP, as it yields a high false-positive rate.
Complications in CWP’s diagnosis

Considering similar medical conditions in confirming the diagnosis of CWP may be useful to reveal any possible misdiagnosis, as other lung diseases may result in similar pathological lesions and/or radiographic features. For example, the chest x-ray in figure 2 shows a miner’s lungs suffering from CWP stage 1. Figure 7 represents a X-ray of healthy lungs and is used in this section for reference.

A mild micronodular mottling can be observed, with diffuse, small Q opacities on both sides of the lungs. Other diseases that may result in an x-ray like this include simple silicosis, miliary tuberculosis or mild interstitial pneumonia.

This final figure shows an X-ray of lungs affected by PMF. A fibrotic mass, with an “angel’s wing” appearance can be observed, due to R opacities merging together. Silico-tuberculosis, disseminated tuberculosis, metastatic lung cancer, and other diffuse infiltrative pulmonary diseases can present similar X-rays. (Sagerman and Miles; 2008)

Therefore, the differential diagnosis of CWP should be done in relation to ILO Classification Guide System and a full occupational history. The other diseases for which Pneumoconiosis is listed as a possible alternative diagnosis in their lists include: histoplasmosis, idiopathic pulmonary fibrosis, sarcoidosis.

Treatment

The effects of simple and complicated CWP on the lungs are irreversible. There is so no specific treatment for the disease available so far, other than palliative and preventive. Chest radiographs are serially monitored in order to prevent further development of the disease (Murray et al; 2005)
References


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