Wesley
Dust Disease
RESEARCH CENTRE

A Clinical, Radiological and Occupational Review of Coal Mine Dust Lung Disease in Queensland

Final Report

Wesley Dust Disease Research Centre

May 2019

RESEARCH INVESTIGATORS

Dr Katrina Newbigin, Chest Radiologist, MBBS, FRANZCR, B-Reader
Dr Newbigin was the Principal Investigator of this project. Dr Newbigin performed all retrospective radiology reviews, wrote the radiology chapter, and provided oversight of all work conducted and the preparation of this report.

Dr Rhiannon McBean, Research Manager, BSc (honours), PhD
Dr McBean managed the research team, conducted the research and was the primary author of this report.

Rex Parsons, Research Assistant, BSc (honours)
Mr Parsons conducted this research, inclusive of undertaking the interviews with subjects, data collection, data cleaning and analyses. Mr Parsons contributed to the creation and design of the questionnaire.

Annaleis Tatkovic, Research Administration Assistant, BSc (honours)
Ms Tatkovic supported the research team in data collection and preparation of this report.

Dr Hervey Lau, Respiratory and General Medicine Registrar, MBBS
Dr Lau provided support in the preparation of chapter four of this report.

Dr David Cleveland, General Practitioner and Occupational Physician Registrar, MBChB, FRACGP
Dr Cleveland provided expert advice to the research team on occupational medicine and questionnaire design.

Prof Tim Driscoll, Professor of Epidemiology and Occupational Medicine, MBBS, MOHS, PhD, FAFOEM, FAFPHM
Prof Driscoll provided expert advice to the research team, in particular on occupational medicine, questionnaire design, data analysis and preparation of this report.

ACKNOWLEDEGMENTS

This work would not have been possible without the study subjects and their doctors. In particular, we would like to thank Dr Robert Edwards (The Wesley Hospital) whose contribution to the medical care of those in the coal industry is unparalleled in Queensland. We also thank Dr Robert Edwards' medical secretaries, Julie Huskic and Sally Price, for their continued support. We would like to thank the rural medical clinics throughout Queensland who provided their facilities. In particular, thank you to Dr Charles Voisot and Bucasia Family Practice for their hospitality. Dr Katrina Newbigin wishes to acknowledge Dr Robert Cohen (Black Lung Centre of Excellence, Chicago, USA) for his ongoing mentorship. Finally, we would like to thank various others for sharing their areas of expertise with us, including Shane Power, Fritz Djukic, Patrick Tyrrell, Dr Bharath Belle, Brad Lucke and Sharif Burra.

EXECUTIVE SUMMARY

This report presents the findings of the research project "A Clinical, Radiological and Occupational Review of Coal Mine Dust Lung Disease (CMDLD) in Queensland". The project was a case series undertaken following the re-identification of CMDLD in Queensland in 2015. The aim of this project was to review recently diagnosed cases of CMDLD to understand the spectrum of diagnoses, the severity of disease and the occupational histories leading to diagnosis.

The study comprised a review of records and the collection of information via questionnaire. Medical information was collected to confirm the diagnosis of CMDLD. This included a review of medical charts, imaging and spirometry from the point of diagnosis. Questionnaires were used to collect in-depth information on the individual's occupational history and their current respiratory health. The occupational history questionnaire utilised was developed specifically for this study while the respiratory questionnaires used internationally-validated questions. Seventy-nine current or former Queensland coal industry workers, with confirmed CMDLD, were included in the study. Of these 79 subjects, 36 (46%) participated in the questionnaire component. All subjects were male, with a mean age of 59 years (range: 35-90). The first and last year in which any subject was employed in the coal industry was 1955 and 2018, respectively. The majority (74%) of study subjects had worked only in the Queensland coal industry, without any interstate or overseas history of work. The mean tenure of the study subjects in the coal industry was 26 years (range: 6-45). In regards to mine-type, 44% of subjects had worked only in underground coal mining, compared to 27% who had never worked underground (including two subjects who had worked in coal ports only). The remaining 29% of subjects had both underground and open-cut mining experience. One-quarter of the workers reported starting work between 2000 and 2008.

The full spectrum of CMDLD diagnoses was identified in this study group. Diagnoses were coal workers' pneumoconiosis (CWP, n= 27), silicosis (n= 11), mixed dust pneumoconiosis (MDP, n= 18), dust-related diffuse fibrosis (DDF, n= 5) and chronic obstructive pulmonary disease (COPD, n= 22). Four individuals had two diagnoses, with one of these being CWP, MDP or DDF, and the second being COPD. Disease severity, as assessed on medical imaging, ranged from the lower radiological disease stages to advanced disease. Radiologically advanced disease was observed in 30% of subjects and included six cases of progressive massive fibrosis. Unfortunately, due to the nature of this study, we are unable to report on the cause for the relatively high proportion of advanced radiological disease which was observed. However, the authors postulate that delayed medical diagnosis is the most likely cause, given the Coal Mine Worker's Health Scheme in Queensland has been identified as being ineffective between 1984 and 2016. Furthermore, an over-estimation of severity may have occurred, as advanced forms of disease are more easily appreciated on imaging and are thus more likely to be detected.

Disease severity, as assessed on spirometry testing, also ranged from normal to severely abnormal. In the study group, 47% of subjects had normal spirometry, compared to 53% who had abnormal spirometry. In the vast majority of subjects, spirometry was performed after the radiological diagnosis of CMDLD, including seven subjects who had spirometry

performed three (or more) years after the initial diagnosis. This limits the ability of the study to identify useful correlations between radiological and clinical features of CMDLD. In terms of clinical features, the majority of subjects who completed the respiratory questionnaires were symptomatic, with 26/36 subjects reporting breathlessness. It must be noted that a high proportion of the study group were current smokers (10%) or ex-smokers (70%) and this may have contributed to findings on spirometry and clinical symptoms.

Examination of the extent of relationships between various variables reviewed in this study did not identify any correlations. No relationship was observed in the study group between radiological severity, either on chest radiograph or HRCT, and spirometry, or occupational factors, including tenure in the coal industry and type of coal mine worked in ($p > 0.05$ in all comparisons). Further, no relationship was observed in our study group between spirometry values and tenure or coal mine type ($p > 0.05$). The low power of the study means the lack of identified correlations may not adequately represent the true relationships between at least some of these variables. Continued research, including re-analysis of these relationships would be of the utmost interest, as further CMDLD cases are identified and additional data points become available. There remains a need for additional, high-quality longitudinal research before it can be determined whether the findings of this study are reflective of workers within the Queensland coal industry as a whole.

This study provides evidence that CMDLD exists in the Queensland coal industry and provides the first medical insight into these diseases in Queensland in over three decades. The full spectrum of CMDLD diagnoses was observed in this study group, and the information presented on disease severity on radiological and spirometry testing provides valuable insights to the current status of these diseases in coal workers. It is hoped the findings of this study lead to an increased awareness of these diseases and their current status in Queensland; continued improvement in the monitoring and control of dust exposures; and high-quality disease surveillance.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER ONE: INTRODUCTION

This report presents a case series review undertaken following the re-identification of Coal Mine Dust Lung Disease (CMDLD) in Queensland in 2015. This report combines respiratory medicine, radiological findings and occupational histories to present a comprehensive picture of recently identified cases of CMDLD.

1.1 Scope and Aims of the Study

The aim of this report was to review recently diagnosed cases of CMDLD to understand:

1. The spectrum of diagnoses
2. The severity of disease, as assessed on medical imaging and spirometry
3. The respiratory symptoms present
4. The occupational histories prior to diagnosis

This study, and the resulting final report, is targeted at the medical community.

1.2 Coal Mine Dust Lung Disease

CMDLD is defined as an occupational lung disease attributed to the cumulative inhalation of respirable coal mine dust. In general, a history of at least ten years of dust exposure is required to lead to the development of CMDLD [1]. However, in the USA, in recent years, the rapid development of CMDLD has been described in coal miners with as little as five years of exposure [2]. Coal mine dust includes carbon, stone dusts, quartz and silicate particulates which can lead to a range of pathological changes in the lungs. In general terms, the resulting lung changes can be divided into two groups; those which are fibrotic or nodular, and those which are non-nodular. The pneumoconioses are the most well-known of the CMDLD and are associated with small fibrotic nodules; these diseases are coal workers' pneumoconiosis (CWP), silicosis and mixed dust pneumoconiosis (MDP). In severe disease, the pneumoconiosis nodules merge together forming large areas of fibrosis, termed progressive massive fibrosis (PMF). Dust-related diffuse fibrosis (DDF) is characterised by typically widespread pulmonary fibrotic changes. CMDLDs which are not associated with fibrosis or nodules include chronic obstructive pulmonary disease (COPD), encompassing emphysema and chronic bronchitis. CMDLD is, therefore, an umbrella term used to describe a range of distinct histological and clinical diseases that can occur as a consequence of exposure to dust while working in the coal mining industry.

1.3 CMDLD: A Global Health Problem

CMDLDs are a serious health concern around the world; it is estimated that CWP caused 3,200 deaths worldwide in 2017 [3]. In the United States of America (USA), the prevalence of CWP appears to have increased since 2000 [4-6]. The crude prevalence of CWP in the USA was determined in 2005 to be 3%, based on a review of over 29,000 chest radiographs of underground coal miners enrolled in the federal surveillance program between 1996 and 2002 [4]. More recent data, reported in 2018, shows the prevalence of CWP among American underground miners with a tenure of 25 years is 10%; if only miners in the central Appalachia region (Kentucky, Virginia, West Virginia) are included, this value rises to approximately 21% [6]. Further, a resurgence of PMF has also been observed in the central Appalachia region, with the prevalence in miners with 25 years or more tenure now being approximately 3%, the highest prevalence observed in decades [7]. The nodular CMDLDs are known to have a prolonged latency period, meaning that the disease may only appear years after the causative exposure has ceased. In developing countries, CMDLD remains one of the most serious occupational health and safety concerns. For example, in China, over 22,000 new cases of CWP were reported annually between 2003 and 2016 [8]. The prevalence of CWP in China was reported as 6% between 2001 and 2011, with prevalence as high as 10% in locally-owned mines [9]. In many other developing countries, pneumoconiosis is considered an invisible problem as health services and screening programs are limited [10]. At the present time there is no prevalence data available for Australia.

1.4 The Re-identification of CMDLD in Queensland

In the Queensland context, CWP was believed to have been eradicated following the establishment of the Coal Mine Worker's Health Scheme (CMWHS) in the early 1980s. The health scheme was established in Queensland in 1983 to protect the health of those in the coal industry by requiring periodic health assessments. Around the same time (April 1984), a report was published highlighting 75 suspected or confirmed cases of CWP among Queensland coal industry workers [11]. No cases of CWP were identified by the Queensland CMWHS in the 30 years following the 1984 report. This led to the widely accepted belief by coal industry stakeholders that CMDLD had been eradicated. This was dispelled in May 2015 when a case of CWP in a Queensland coal miner was reported to the Queensland Government Department of Natural Resources, Mines and Energy (DNRME). By December 2015, six cases of CWP had been reported to the DNRME. Following the discovery of the initial cases, a review of the design and operation of the respiratory component of the CMWHS was commissioned by DNRME. A review team from Monash University and the University of Illinois at Chicago was engaged to conduct the review. This independent review revealed "major systemic failures at virtually all levels of the design and operation of the respiratory component of the current CMWHS" [12]. Examples of the recommendations made in the final report to address system failures included reforms to create a more clearly articulated purpose of the scheme and the inclusion of former coal workers, including retirees [12]. A parliamentary enquiry was also commissioned to investigate the re-identification of CWP in Queensland. The final report of the parliamentary enquiry identified catastrophic failure, at almost every level, of the regulatory system intended to protect the health and safety of coal workers in Queensland [13]. The report concluded that significant reform of the regulatory framework for coal mining in Queensland was urgently needed. Following these independent reviews/reports, the CMWHS has undergone modifications. These include the health scheme now including chest radiograph and spirometry testing for all workers within the scheme, coverage for former and retired coal mine workers, the mandatory register of independently approved doctors and medical providers and the inclusion of clear guidelines for screening spirometry and chest radiographs.

1.5 Coal Mining in Queensland

1.5.1 Overview of the Industry

Coal mining has been a historical occupation in Queensland, with sites in Ipswich being mined for almost 200 years [14]. There are currently about 50 coal mines in operation across Queensland, inclusive of ten underground mines [13]. Over the thirty years in which CMDLD was not detected in Queensland, the coal mining industry grew significantly in terms of production. The main reason for this being the commencement of mining on the largest coal deposit in Queensland, the Bowen Basin [15]. The rate of employment in the sector has increased over time, with the Queensland coal mining industry currently employing over 30,000 workers [16]. Accordingly, both coal production and export revenue has increased such that coal mining has become a multibillion-dollar industry [16].

1.5.2 Occupational Exposure Limits

The dusts which contain respirable coal and crystalline silica have accumulative effects, increasing the risk associated with exposure over extended lengths of time [17]. Respirable materials have an occupational exposure limit (OEL), an upper limit of average dust exposure for a worker over an 8-hour shift [17, 18]. Occupational exposure limits identify a level below which the majority of workers should not develop adverse health effects arising from the exposure. OELs do not represent a "safe" level of exposure, and it is important that exposures are kept as low as reasonably practicable. Queensland's OEL for coal mine dust was 3.0 mg/m^3 prior to November 2018, at which time it was reduced to 2.5 mg/m^3 [19]. Australia's respirable crystalline silica (RCS) OEL of 0.1 mg/m^3 [18]. Within this study we did not review the level of dust subjects with CMDLD were exposure to.

1.6 Summary

To summarise, the re-identification of CMDLD in Queensland is a complex and multi-layered issue. The key complexities from the medical perspective are the latent nature of CMDLD on the background of an inadequate health surveillance scheme. This study, although not providing any information on the prevalence of CMDLD in Queensland, planned to shed light on the current spectrum of disease for the first time in 30 years by reviewing clinical, radiological and occupational aspects of current and former Queensland coal industry workers diagnosed with a CMDLD since the re-emergence in 2015.

CHAPTER TWO: OVERVIEW OF STUDY METHODS AND STUDY GROUP

2.1 Nature of Study

This study was a case series review of individuals identified as having a CMDLD caused by occupational exposure to coal mine dust in Queensland. The study comprised two components as explained briefly here and in further detail below:

- A review of medical information to confirm the diagnosis of CMDLD. This included a review of available medical imaging and spirometry taken at the time of diagnosis. Medical charts or summary letters from respiratory physicians were also collected where possible to provide an overview of the subject's general health, their diagnosis pathway and whether they were a current or former coal industry worker.
- Questionnaires were used to collect in-depth information on the individual's occupational history and their current respiratory status. The occupational history questionnaire that was utilised was developed specifically for this study as no suitable existing questionnaire was identified. Internationally-validated questions were used to assess respiratory symptoms.

2.2 Definition of Diagnoses Utilised in Study

The CMDLD diagnoses utilised in this study are defined here:

- Coal workers' pneumoconiosis (CWP): Occupational lung disease associated with inhalation of coal mine dust. The characteristic lesions of CWP typically form around respiratory bronchioles and are termed "coal macules". These macules are comprised of closely packed dust-laden macrophages, surrounded by a small network of collagen fibres and fibroblasts [20].

- Silicosis: Occupational lung disease associated with the inhalation of RCS. Silicotic nodules are formed following the engulfment of RCS by macrophages. Silicotic nodules are characterised by dense collagen whorls which reflect the increased inflammatory response and fibrogenicity associated with RCS compared to coal dust.

- Mixed dust pneumoconiosis (MDP): Occupational lung disease associated with the inhalation of mixed dust, for example, coal mine dust containing RCS. Pathologically, MDP nodules contain more mineral dust and collagen than CWP nodules, and do not have the collagen whorls associated with silicotic nodules [21]. These MDP nodules typically occur alongside silicotic nodules and CWP nodules, giving a hybrid pattern.

- Progressive massive fibrosis (PMF): A radiological term, rather than a stand-alone clinical diagnosis, for coalesced nodules greater than 1 cm in size. PMF occurs in individuals with a nodular CMDLD diagnosis and is indicative of the highest disease severity. PMF is progressive, with the fibrotic nodules continuing to enlarge, and be drawn together, resulting in the loss of lung volume even in the absence of further dust exposure [22].

- Dust-related diffuse fibrosis (DDF): Pathologically, DDF manifests as fibrosis bridging together pulmonary nodules, typically with pigmented interlobular septal thickening [23]. DDF is often lower zone predominant and, therefore, can mimic the fibrotic lung conditions idiopathic pulmonary fibrosis (IPF) and asbestosis. Additional features of DDF include lower lobe interstitial opacities, honeycombing and traction bronchiectasis [24, 25].

- Chronic obstructive pulmonary disease (COPD): Chronic airflow obstruction that is not fully reversible is the defining feature in the diagnosis of COPD [26, 27]. The degree of airway obstruction is determined by spirometry. On spirometry, an FEV1/FVC ratio <0.7 is required for the diagnosis of COPD [27]. Clinically, COPD is characterised by increasing breathlessness and may present with other symptoms including cough and wheezing [28]. COPD is an umbrella term encompassing emphysema and chronic bronchitis. Historically, the terms emphysema and chronic bronchitis were used in addition to, or instead of COPD, however, the World Health Organisation (WHO) advises that these terms should no longer be used [29]. Given there are multiple recognised causes of COPD, including cigarette smoking, it must be noted that a diagnosis of COPD was only utilised in this study if coal mine dust was considered the significant contributing factor to disease development.

The diagnoses used within this report are those given by the individual's treating respiratory physician. The treating specialists determined diagnoses based on standard clinical practices, medical imaging, occupational history and spirometry. Histopathological investigations were not always conducted to distinguish between CWP, silicotic and MDP nodules.

Throughout this report, sub-analysis of results has been undertaken in which diagnoses are grouped together as "nodular CMDLD". Nodular CMDLD hereby refers to CWP, silicosis and MDP. The nodular CMDLDs are those that are characterised by small opaque nodules on medical imaging (see Figures 8 and 11 for representative images depicting nodules).

2.3 Ethics Approval and Data Security

Ethics approval for this study was granted by the UnitingCare Health Human Research Ethics Committee (reference: 2016.26.206). The ethics committee waived the need for informed consent for the retrospective components of this study, which included a review of medical imaging and medical charts. Following confirmation of CMDLD diagnosis, each individual was contacted by the research team and asked to participate in the questionnaire component of this study. Written informed consent was obtained before an individual completed the questionnaires.

Patient confidentiality was maintained at all times. Identified medical or personal data was not shared outside of the research team. All data was stored on password-protected laptops and on a secure server.

2.4 Case Identification Methodology and Inclusion Criteria

Case identification was done in one of two ways; either the research team was notified of a CMDLD case by the treating respiratory physician or by the DNRME. Following identification of a CMDLD case, the research team undertook case confirmation by retrospectively collating and reviewing available medical imaging and medical charts, inclusive of spirometry. The following inclusion criteria had to be met within the retrospective review for a case to be included in this study:

- Evidence that the individual was a current or former coal industry worker
- Diagnosis of CMDLD made by the treating respiratory physician
- For nodular CMDLDs: radiological appearance supportive of the diagnosis
- For COPD cases only: spirometry supportive of the diagnosis

Once a case of CMDLD had been accepted into the study, the individual was contacted and asked to provide informed consent to participate in the questionnaire component of this study. Meeting each individual to conduct the questionnaire-based interview face-to-face was the preference of the research team; if this was not possible, an electronic link to the questionnaire was emailed to the individual to allow completion of the questionnaire online.

2.5 The Study Group

The research team was notified about 142 dust-induced lung disease cases (Figure 1, blue box). Of these, 63 could not be confirmed as meeting the inclusion criteria for the study (Figure 1, red box). Reasons for this were records not being accessible (n= 23); records being accessible but no definite CMDLD diagnosis made by the respiratory physician (n= 15); and confirmation of an occupational lung disease not related to coal dust exposure (n= 25).

In total, 79 subjects with confirmed CMDLD were included in the study (Figure 1, green boxes). All subjects were male, with a mean age of 58.9 years (range: 35-90). Medical imaging was available for review in all subjects; basic occupational information was available for 75 subjects; and spirometry was available for 77 subjects. The CMDLD diagnoses in this study group were CWP (n= 27), silicosis (n= 11), MDP (n= 18), DDF (n= 5) and COPD (n= 22). Four individuals had a combination of a COPD diagnosis with either a nodular CMDLD or DDF. Six individuals had a nodular CMDLD with PMF.

The research team attempted to contact all individuals with confirmed CMDLD to invite them to participate in the questionnaire component of this study. Contact was not possible for 13 individuals. Reasons for this were no current contact details being available or the individual being deceased (n= 4). Where contact was made, a total of 24 individuals declined to participate in the questionnaire component of this study. The majority of individuals reported declining due to anxiety or depression regarding diagnosis; poor health; and an unwillingness to participate because of active legal matters. There were six individuals who consented to participate but, for logistical and/or time constraints, were not able to complete the questionnaire before preparation of this report (Figure 1, yellow box). Individuals who could not be contacted, and those who declined to complete the questionnaire, were included in the other component of this study only. In total, in-depth respiratory and occupational information was collected for 36 subjects (Figure 1, orange box).

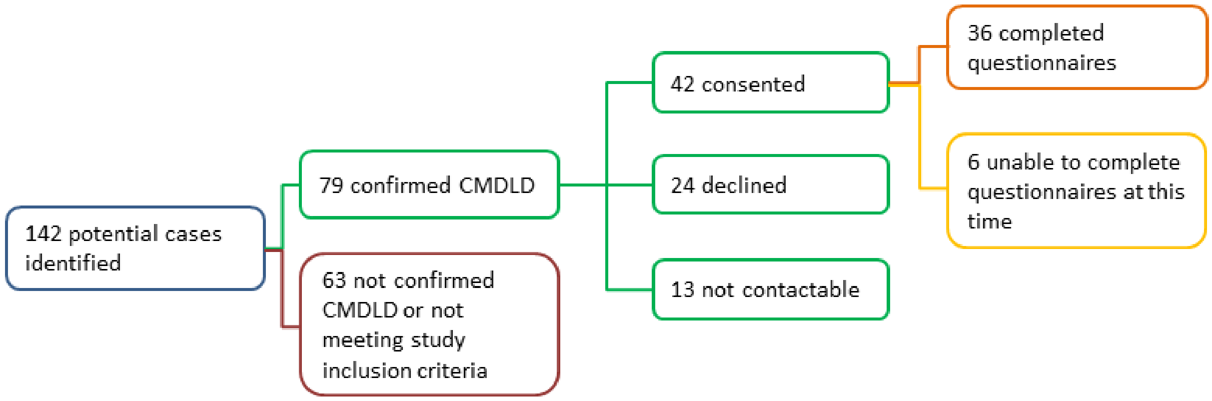


Figure 1: Process of case identification and refinement of the study group.

CHAPTER THREE: RADIOLOGY

3.1 Background

Coal workers' pneumoconiosis, MDP and silicosis are the pneumoconioses, or occupational lung diseases, that are associated with small nodules of scar tissue in the lungs of dust-exposed workers. On chest radiographs or high-resolution computed tomography (HRCT) of the chest, these nodular scars appear as small, "dot-like" opacities. The size, shape and profusion of these opacities can be graded to reflect the severity of disease using the International Labour Office (ILO) Classification System and the International Classification of HRCT for Occupational and Environmental Respiratory Diseases (ICOERD). The ILO system is a validated screening tool that grades the profusion of these nodules, as an indicator for disease severity, on chest radiograph across a 12-point scale (Appendix 1). This grading scale reflects the increasing likelihood of lung impairment and development of PMF. Literature reports 12% of individuals with advanced pneumoconiosis (ILO ≥2/1) will develop PMF within five years [30]. The ICOERD is used to grade pneumoconiosis on HRCT imaging of the chest across a 19-point scale (Appendix 2). HRCT of the chest is more sensitive and specific for early signs of pneumoconiosis, compared to chest radiographs, due to the increased spatial resolution and 3D nature of HRCT imaging [31].

The higher detail provided by HRCT imaging allows for the analysis of radiological patterns associated with specific CMDLD diagnoses. For example, the opacities associated with silicosis are rounder, more sharply defined and denser than those associated with CWP. This relates to the more intense fibrotic inflammatory response that occurs with RCS inhalation [32]. Additional imaging features which are typical of silicosis include pseudoplaques (the confluence of micronodules in the subpleural aspect of the lung that mimics the appearance of asbestos-related pleural plaques), lymph node calcification, and the rounder, denser morphology of pulmonary nodules ('q' or 'r' type opacities) [32]. Unlike the ILO system, the ICOERD system also grades the radiological severity of emphysema and fibrosis. Both imaging classification systems are associated with high intra-/inter-reliability and are widely used internationally for occupational lung disease screening programs, clinical diagnosis, and epidemiological research [33]. The aim of this component of the project was to review individuals recently diagnosed with CMDLD to understand the spectrum of diagnoses and the severity of disease on medical imaging.

3.2 Methods

The majority of subjects in this series (74/79) had both a chest radiograph and HRCT of the chest from the time of diagnosis available for retrospective review. Only a chest radiograph was available for four subjects, and one subject had only a chest HRCT. All available imaging was reviewed by a chest radiologist (KN) who holds current sub-specialist accreditation for the ILO classification system (B-reader certification), using the 2011 ILO reference standards and the ICOERD grading scales [33, 34]. The reviewing radiologist was blinded to detailed occupational history and spirometry results at the time of radiological review. An ILO profusion grade of ≥1/0 was considered the threshold for calling a chest radiograph positive for nodular CMDLD. The positive threshold for nodular CMDLD on HRCT of the chest was considered an ICOERD summated nodular grade of ≥2. Subjects with a negative chest radiograph (ILO <1/0) but positive HRCT (nodular grade ≥2) were considered CMDLD positive given the increased sensitivity for HRCT to detect early pneumoconiosis.

Radiological imaging features relevant to occupational lung diseases were also recorded, including coalescence of nodules and the features associated with RCS exposure as outlined above. The analysis was conducted using descriptive statistics and was performed for the whole study group and in sub-groups based on clinical diagnosis.

3.3 Results

3.3.1 Radiological Analysis of the Study Group

The majority of subjects (71%) had a nodular radiological pattern of disease (Table 1); three of these individuals, with a diagnosis of nodular CMDLD, also had a secondary diagnosis of COPD. Five subjects (6%) had a radiological pattern of DDF; one of these subjects also had a secondary diagnosis of COPD. The remaining eighteen subjects (23%) had COPD, either without any pulmonary nodules (n= 14) or with nodules but without meeting the criteria for a nodular disease (n= 4).

Table 1. The study group by clinical and radiological diagnosis. Subjects are divided into sub-categories of nodular and non-nodular CMDLD diagnoses.

Disease type	Nodular CMDLD			DDF	COPD	Multiple CMDLD			Total
Total	53			4	18	4			79
Diagnosis	CWP	MDP	Silicosis	DDF	COPD only	COPD + CWP	COPD + MDP	COPD + DDF	
Number	26	16	11	4	18	1	2	1	79

Of the subjects who had profusion grade data available (n= 78), the most common ILO classification was grade 1, with 56% graded as ILO 1/0, 1/1 or 1/2. There were six cases of PMF, two subjects were observed with each nodular CMDLD - CWP (ILO 1/0 and 1/2), silicosis (ILO 1/2 and 2/1) and MDP (ILO 1/2 and 2/1). Advanced radiological disease, defined as ILO grades of ≥2/1 or PMF, was observed in 23 cases in the study group (30%, Table 2). There was little difference between the mean age of individuals with low-grade disease (58.3 years) and those with advanced radiological disease (60.2 years).

Table 2. The study group with advanced radiological disease (ILO grade ≥2/1 or PMF)

CMDLD Diagnosis	Number (%) within each CMDLD
CWP	4/27 (14.8%)
MDP	8/18 (44.4%)
Silicosis	7/11 (63.6%)
DDF	4/5 (80.0%)
COPD only	0/17
Total	23/78 (29.5%)

Subjects with multiple diagnoses, inclusive of COPD, are included in this table under their primary diagnosis.

On chest HRCT, the mean ICOERD nodular grade of subjects with a nodular CMDLD was 7.2 (n= 53, range: 2-16). Some subjects with a nodular CMDLD also demonstrated radiological evidence of emphysema (n= 10). The radiological grade of emphysema was highest in subjects with a clinical diagnosis of COPD (n= 21, mean ICOERD emphysema grade: 5.8, range: 0-16), compared to other disease sub-groups (Table 3). Chest HRCT imaging found that coalescence, the preceding sign to PMF, was present in five subjects. Radiological features which suggest RCS exposure were observed on chest radiograph and HRCT, including lymph node calcification (17%), predominate rounded nodules larger than 1.5 mm in diameter ("r" or "q" types) (46%) or subpleural nodularity/pseudoplaques (31%). Over half (60%) of the subjects in the study group demonstrated at least one of these three radiological features.

3.3.2 Radiological Analysis by Clinical Diagnosis

The radiological grades and patterns of disease were also analysed by clinical diagnosis, including the pneumoconioses, CWP (27/79), MDP (18/79) and silicosis (11/79). Subjects with CWP were the most likely, of the nodular CMDLDs, to demonstrate a lower radiological severity grade, as measured by both the ILO and ICOERD systems (Figure 2, Table 3). In contrast, subjects with silicosis demonstrated the highest radiological grades. The mean and range of radiological grades for both the ILO and ICOERD systems demonstrated concordance between the two systems (adjusted r^2= 0.52, p <0.001, Figure 3). Small, rounded opacities ('p' and 'q' opacities) were the most common predominant nodular type observed (44/56, 79%) within the nodular CMDLD group. Large round pulmonary nodules ('r' opacities) were not observed in anyone with CWP but were seen in three individuals in each of the MDP and silicosis categories.

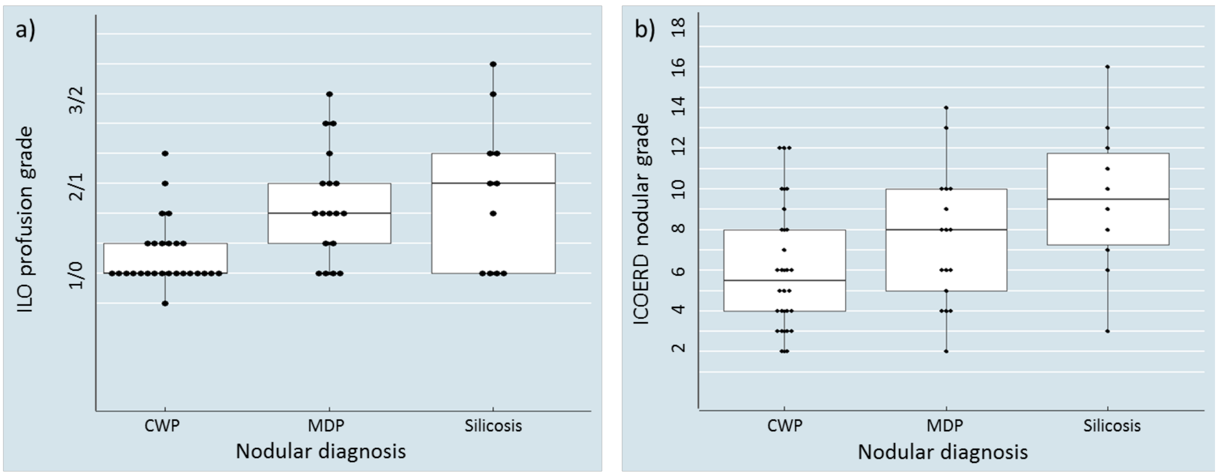


Figure 2: Radiological grades for each sub-category of nodular CMDLD diagnoses. ILO profusion grade on chest radiograph (2a) and HRCT ICOERD nodular grade (2b). For interpretation of box and whisker plots, see Appendix 3.

Table 3. Radiological ILO (n= 78) and ICOERD (n= 75) grades for each sub-category of CMDLD.

Grading system		CMDLD diagnosis: CWP (n= 27)	MDP (n= 18)	Silicosis (n= 11)	DDF (n= 5)	COPD (n= 21)	Total (n= 78)
ILO Profusion	0/0	0	0	0	0	11	11
	0/1	1*	0	0	0	2	3
	1/0	16	4	4	1	5	28
	1/1	6	2	0	0	1	9
	1/2	2	5	1	0	1	8
	2/1	1	3	2	2	0	8
	2/2	1	1	2	0	0	4
	2/3	0	2	0	1	0	3
	3/2	0	1	1	1	1	3
	3/3	0	0	1	0	0	1
Mean ILO (range)		1/0 (0/1-2/2)	1/2 (1/0-3/2)	2/1 (1/0-3/3)	2/1 (1/0-3/2)	0/0 (0/0-3/2)	1/1 (0/0-3/3)
Mean ICOERD (range)	Emphysema	0.8 (0-18)	2.6 (0-16)	0.3 (0-2)	2.8 (0-8)	5.8 (0-16)	2.4 (0-18)
	Fibrosis	0.4 (0-6)	0.8 (0-8)	1.1 (0-6)	8.6 (5-13)	1.1 (0-8)	1.1 (0-13)
	Nodular	6.1 (0-12)	7.5 (2-14)	9.5 (3-16)	2.4 (0-6)	1.8 (0-14)	5.5 (0-16)

*negative chest radiograph but positive chest HRCT (ICOERD nodular grade >2).
Four subjects with multiple diagnoses are displayed in each relevant CMDLD diagnosis column, and counted once within the total column.

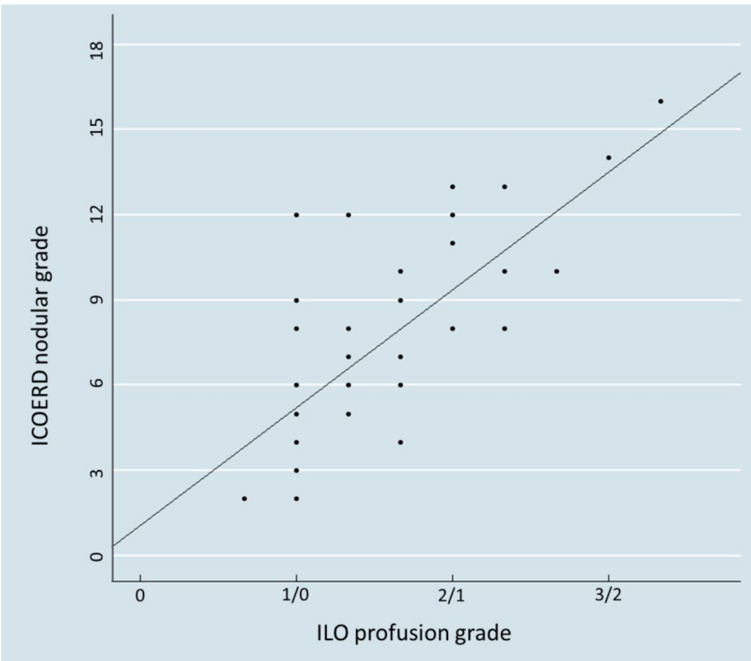


Figure 3: Comparison of radiological grades between the two grading systems for nodular CMDLD diagnoses (adjusted r^2= 0.52, p <0.001).

3.4 Discussion

The broad spectrum of dust-related clinical diseases that occur in coal industry workers was observed in this case series. The most common forms of CMDLD seen in this series were the nodular forms. Selection bias may in part account for this given these instances of CMDLD were detected due to the recent changes which have made chest radiographs compulsory for all coal mine workers within the CMWHS and are specific to dust exposure. In comparison, COPD may potentially be under-represented in our series relating to the difficulty in attributing underlying cause of COPD as the presentation of smoking and dust-related COPD is identical. The high proportion of subjects with a nodular lung disease, however, allowed for assessment of disease severity using the ILO classification system and, therefore, comparisons can be made between this case series and prior research.

The majority of men diagnosed with a nodular form of CMDLD were in the lower radiological stages of the possible disease course (ILO <2/1). An early diagnosis was often the case for those with CWP, where 89% demonstrated grade 1 radiographic disease. Workers who were exposed to a combination of coal and RCS dusts during their careers, as assumed based on clinical diagnoses of MDP or silicosis, had higher mean grades of radiological disease compared to workers with CWP. Approximately one third (30%) of the subjects were diagnosed at a stage of their disease considered an advanced radiological grade; this high proportion of advanced lung disease is clearly concerning. However, it cannot be determined whether this reflects the situation in the wider Queensland coal mining workforce as only individuals referred to the researchers were included in this study. In fact, it is likely that over-estimation of severity has occurred as advanced forms of disease are more easily appreciated on imaging and, therefore, more likely to be associated with clinical symptoms resulting in the patient being given a diagnosis of CMDLD.

This case series is the first research investigating CMDLD in Queensland since the 1984 review of 7,784 current and retired coal workers by Dr Rathus and Dr Abrahams [11]. As the ILO grading system was used in the prior report, some comparisons between the two studies can be made. In the 1984 review, 75 individuals with nodular pneumoconiosis were identified, with 67% observed to have an ILO ≤1/2, and 33% having an ILO ≥2/1. Considering the technological advances that have occurred in the mining industry since 1984, the high proportion of advanced radiological disease observed in the current study group is a matter of concern. Furthermore, only a small number of international studies have similar rates of advanced radiological disease. The proportion of CMDLD subjects with advanced disease is similar to published international data; for example, 11 of 30 CMDLD subjects identified in Virginia (USA) had an ILO grade ≥2/1; and a Chinese study found that 143 of 595 subjects with CMDLD had grade 2 or 3 disease [35, 36].

Unfortunately, due to the nature of this study, we are unable to report on the cause for the relatively high proportion of advanced radiological disease which was observed. However, the authors postulate that delayed medical diagnosis is the most likely cause, given the CMWHS in Queensland has been identified as being ineffective between 1984 and 2016 [12, 13]. Internationally in the USA, numerous reasons for more advanced disease have been determined, including the small size of mining operations, narrow seam mining and excessive exposure to RCS [4, 37]. Two of these described factors are not applicable to Queensland, where coal mines are large scale operations of thick seams.

Given that more than half (60%) of the subjects in this study demonstrated at least one radiological sign associated with RCS exposure, it is possible that this form of dust contributed significantly to the spectrum of severities observed. RCS is more hazardous than coal dust, and has been associated with faster disease progression, higher grades of disease and greater risk of PMF when compared to chronic exposure to coal dust alone [38, 39]. This small case series, therefore, raises the need for further research to understand the true prevalence of advanced pneumoconiosis and the possible causes of it in the Queensland (and Australian) context. There remains a need for additional, high-quality longitudinal research before it can be determined whether the radiological findings of this study are reflective of the Queensland coal mining community as a whole.

CHAPTER FOUR: SPIROMETRY AND RESPIRATORY QUESTIONNAIRES

4.1 Background

Respiratory symptoms and lung function, are key measures in the understanding of an individual's respiratory health. Within this study, objective and subjective measurements were obtained to build a comprehensive picture of the respiratory health of subjects recently diagnosed with a CMDLD in Queensland.

Spirometry is a dynamic test of lung function. It measures how much (volume) and how quickly (flow) air can be moved out of the lungs. An individual's result is determined by their lung size, airway calibre, and respiratory muscle strength. It is used as both a screening test of general respiratory health and for monitoring the progression of lung diseases over time. When used in conjunction with clinical assessment, spirometry becomes an invaluable tool for detecting and evaluating diseases of the respiratory system [40]. The key parameters used in the interpretation of spirometry are the forced vital capacity (FVC), which is the maximum volume of air that can be exhaled after a full inspiration, and the forced expiratory volume in one second (FEV1), which is the volume exhaled in the first second of an FVC manoeuvre.

Defects in respiratory ventilation can be grouped broadly into two categories: obstructive and restrictive. Spirometry is the most important test in diagnosing obstructive defects. Patients with obstructive defects are unable to exhale quickly due to a disproportionate reduction in maximal airflow out of the lungs relative to the maximal volume of the lungs [40]. Such airway narrowing can be due to excessive mucus production, airway inflammation, and bronchial smooth muscle contraction, as in asthma and chronic bronchitis, or due to the dynamic collapse of the airways, as in COPD. In contrast, a restrictive defect is a reduction in the volume of the lungs. This can occur in those with scarred lung tissue (fibrosis), pleural and chest wall disease, or weak respiratory muscles. While spirometry cannot be used to formally diagnose a restrictive defect, when changes are observed, it can be suspected.

In addition to the review of the spirometry testing performed at the time of diagnosis, assessments encompassing respiratory health were conducted. The assessments were undertaken by utilising three validated tools, described here.

4.1.1 Modified Medical Research Council Dyspnoea Scale

The modified Medical Research Council (mMRC) Dyspnoea Scale assesses breathlessness via a five-point scale ranging from no respiratory disability (grade 0) to almost complete incapacity (grade 4). The mMRC Dyspnoea Scale has been in broad use after the first iteration was developed to study the respiratory problems of Welsh coal miners in the 1940s [41]. The scale does not quantify breathlessness itself, but rather quantifies whether breathlessness occurs when it should not.

4.1.2 The Medical Research Council Questionnaire

The second respiratory assessment used in this study was the Medical Research Council Questionnaire (MRCQ), version 1976 [42]. The MRCQ was developed as a tool to study respiratory epidemiology. It comprises 17 questions on respiratory symptoms inclusive of cough, phlegm, breathlessness, wheeze, and chest illnesses, now and during the past two years, in addition to detailed questions on smoking history.

4.1.3 Clinical COPD Questionnaire
The third respiratory assessment used was the Clinical COPD Questionnaire (CCQ), a health-related quality of life questionnaire. The CCQ was originally created to measure clinical health status in patients, including symptoms of the airways, limitation of physical activity, and emotional dysfunction [43]. The CCQ is comprised of ten items and was designed to be a simple tool suitable for routine use in clinical practice. It has questions on symptoms, functional state and mental state. Each question is scored from 0 to 6 (0= no impairment) and a total score is calculated by summing the scores of the individual items and dividing by 10, giving a total score between 0 and 6, with higher scores representing a worse health-related quality of life.

The aim of this component of the project was to review subjects with a recently diagnosed CMDLD to understand the severity of disease, as assessed by spirometry and the respiratory symptoms present.

4.2 Methods

4.2.1 Spirometry Methods
Copies of spirometry reports were obtained from the treating doctor who attended to the subject as part of the CMWHS pathway. The majority of spirometry reports were available in electronic format from one Queensland provider. In circumstances where electronic copies were not available, hard copies were obtained from a subject’s medical chart.

Interpretation of the spirometry results was performed in accordance with the Thoracic Society of Australia and New Zealand (TSANZ) Algorithm for Interpretation of Spirometry in Coal Workers (Appendix 4). Using this algorithm, individuals were categorised into three groups: 1) normal; 2) abnormal: obstructive pattern; and 3) abnormal: restrictive pattern. Individuals were classified as having an obstructive pattern if the ratio of the FEV1 to FVC was below the predicted lower limit of normal (LLN) or ≤70 percent of the predicted value. The percentage of the recorded FEV1 relative to its predicted value was used to determine the severity of obstruction, with greater than 60% being mild, 40-59% moderate, and less than 40% being severe. A restrictive pattern was defined as an FVC below the predicted lower limit of normal. Predicted values take into account an individual’s age, sex, height and ethnicity.

4.2.2 Respiratory Questionnaire Methods
The three questionnaires were delivered during the interviews conducted with subjects. A detailed smoking history was collected within the MRCQ. For the purposes of this report, subjects were categorised as current smokers, ex-smokers or never-smokers using the following criteria:

- Current smokers were subjects who reported smoking at least one cigarette daily for at least one year at the time of the questionnaire.

- Ex-smokers were subjects who reported having smoked at least one cigarette daily for at least one year and who at the time of the questionnaire had not smoked for six months or more.
- Never-smokers were those who did not fit either of these criteria.

Life-long smoking history was expressed as pack-years by multiplying the daily cigarette packet consumption by the years of regular smoking. One cigarette packet was defined as containing 20 cigarettes.

4.3 Results

4.3.1 Spirometry Results for the Study Group

Spirometry records were available for 77 of the 79 subjects in this study. Of 77 available records, 72 were complete reports. Of the 72 subjects with complete data, 47% had normal spirometry (Table 4). An obstructive pattern of disease was the most common in the 53% with abnormal spirometry (87%), followed by a restrictive pattern (13%). Most individuals with obstruction had borderline-normal (39%) or mild disease (36%), with smaller numbers of subjects affected by moderate (12%) and severe disease (12%). Diagnoses of CWP and silicosis were associated solely with an obstructive pattern, while DDF was associated with a restrictive pattern only.

Table 4: Spirometry classification (*n*, (%)) and values (mean (range)) for subjects with spirometry results available.

	CMDLD diagnosis					
Spirometry classification	CWP (n= 25)	Silicosis (n= 10)	MDP (n= 16)	COPD (n= 19)	DDF (n= 5)	Total (n= 72)
Normal	13 (52.0%)	8 (80.0%)	5 (31.3%)	7 (36.8%)	2 (40.0%)	34 (47.2%)
Abnormal	12 (48.0%)	2 (20.0%)	11 (68.8%)	12 (63.2%)	3 (60.0%)	38 (52.7%)
Restrictive	0	0	1 (6.3%)	1 (5.3%)	3 (6.0%)	5 (6.9%)
Obstructive	7 (28.0%)	1 (10.0%)	6 (37.5%)	8 (42.1%)	0	33 (45.8%)
Borderline	5 (20.0%)	1 (10.0%)	4 (25.0%)	3 (15.8%)	0	13 (39.4%)
Mild	6 (24.0%)	0	4 (25.0%)	2 (10.5%)	0	12 (36.4%)
Moderate	1 (4.0%)	0	0	4 (21.1%)	0	4 (12.1%)
Severe	0	1 (10.0%)	2 (12.5%)	2 (10.5%)	0	4 (12.1%)
Spirometry values*	CWP (n= 27)	Silicosis (n= 10)	MDP (n= 16)	COPD (n= 21)	DDF (n= 5)	Total (n= 77)
FEV1%	86.9 (49.9 -115.4)	86.2 (24.0- 117.9)	81.7 (17.4-127.4)	70.3 (28.2-101.0)	74.6 (74.6-87.3)	81.3 (17.4-127.4)
FVC%	99.7 (76.9 - 141.2)	95.7 (77 - 116.2)	90.2 (44.5 - 132.6)	84.8 (49.5 - 115.8)	71.4 (42.0-99.7)	92.3 (42.0-141.2)
FEV1/FVC	69.4 (41.7-84.7)	70.2 (24.0-84.0)	69.1 (29.6-86.7)	64.3 (34.0-85.3)	81.3 (74.6-87.3)	69.1 (24.0-87.3)

Results are displayed as the overall study group and by clinical diagnosis. Four subjects with multiple diagnoses are displayed in each relevant CMDLD diagnosis column, and counted once within the total column.
*Spirometry values are displayed as mean (range)

4.3.2 Breathlessness (mMRC Dyspnoea Scale)

Of those who participated in the questionnaires (n= 36), 72% of subjects reported breathlessness. Of the 26 subjects who reported breathlessness (mMRC dyspnoea grade >0), eight reported a grade of 1, five reported a grade of 2, 13 reported a grade of 3 and no subjects reported the most severe grade of 4.

Analysis of breathlessness within each diagnosis group showed individuals with COPD and DDF more frequently reported a higher grade of breathlessness - 78% of subjects with COPD and 2/3 subjects with DDF reporting a breathlessness grade of 3 (Table 5).

Table 5: mMRC Dyspnoea Scale results.

Score	CMDLD diagnosis					
	CWP (n= 11)	Silicosis (n= 6)	MDP (n= 9)	COPD (n= 9)	DDF (n= 3)	Total (n= 36)
0	5 (45.4%)	2 (33.3%)	1 (11.1%)	1 (11.1%)	1 (33.3%)	10 (27.7%)
1	2 (18.2%)	2 (33.3%)	3 (33.3%)	1 (11.1%)	0	8 (22.2%)
2	2 (18.2%)	1 (16.7%)	2 (22.2%)	0	0	5 (13.9%)
3	2 (18.2%)	1 (16.7%)	3 (33.3%)	7 (77.8%)	2 (66.7%)	13 (36.1%)
4	0	0	0	0	0	0

Thirty-six subjects completed the mMRC Dyspnoea Scale. Two subjects with multiple diagnoses are displayed in each relevant CMDLD diagnosis column, and counted once within the total column.

4.3.3 Respiratory Symptoms (MRCQ)

Thirty-six subjects answered questions about respiratory symptoms through the questionnaires (Table 6) and 80% of subjects reported that they were symptomatic. Cough was the most common respiratory symptom, reported by 75% of the study group; 36% of subjects reported ever having pneumonia, and 14% reported ever having asthma.

Table 6: MRCQ respiratory symptoms score results.

Respiratory symptoms	CMDLD diagnosis					
	CWP (n= 11)	Silicosis (n= 6)	MDP (n= 9)	COPD (n= 9)	DDF (n= 3)	Total (n= 36)
Symptomatic	8 (72.7%)	3 (50.0%)	9 (100%)	8 (88.9%)	3 (100%)	29 (80.4%)
Cough	7 (63.6%)	3 (50.0%)	0	8 (88.9%)	2 (66.7%)	27 (75.0%)
Phlegm	6 (54.5%)	3 (50.0%)	7 (77.8%)	6 (66.7%)	0	23 (63.8%)
Wheeze	4 (36.4%)	1 (33.3%)	5 (55.6%)	5 (55.6%)	1 (33.3%)	15 (41.7%)
Pneumonia	2 (18.2%)	3 (50.0%)	3 (33.3%)	6 (66.7%)	1 (33.3%)	13 (36.1%)
Asthma	2 (18.2%)	0	2 (22.2%)	3 (33.3%)	0	5 (13.8%)

Thirty-six subjects completed the MRC Respiratory Symptoms questionnaire. Two subjects with multiple diagnoses are displayed in each relevant CMDLD diagnosis column, and counted once within the total column.

4.3.4 Health-Related Quality of Life (CCQ)

The majority of individuals who completed the CCQ reported some impairment of quality of life, indicated by a score of 1 or higher (89%) (Table7). The most frequent score reported was 2 (25%), the proportion only a little higher than for scores of 1 and 3 (22% each), correlating with some impairment of quality of life. The highest score reported in this study was 5, reported by one subject. In terms of the individual categories, about half of the subjects had a functional score of 0 or 1 and a mental state score of 0 or 1. Symptoms scores tended to be higher, but the most common symptoms score was 1 (Table 7).

Table 7: Health-related quality of life score as assessed by the COPD Clinical Questionnaire.

	CMDLD diagnosis					
Total score	CWP (n= 11)	Silicosis (n= 6)	MDP (n= 9)	COPD (n= 9)	DDF (n= 3)	Total (n= 36)
0	3 (27.3%)	0	0	1 (11.1%)	0	4 (11.1%)
1	3 (27.3%)	2 (33.3%)	0	1 (11.1%)	2 (66.7%)	8 (22.2%)
2	3 (27.3%)	3 (50.0%)	3 (33.3%)	0	0	9 (25.0%)
3	0	1 (16.7%)	3 (33.3%)	4 (44.4%)	1 (33.3%)	8 (22.2%)
4	2 (18.2%)	0	2 (22.2%)	3 (33.3%)	0	6 (16.7%)
5	0	0	1 (11.1%)	0	0	1 (2.8%)
6	0	0	0	0	0	0
Functional state score	CWP (n= 11)	Silicosis (n= 6)	MDP (n= 9)	COPD (n= 9)	DDF (n= 3)	Total (n= 36)
0	4 (36.4%)	0	0	2 (22.2%)	1 (33.3%)	7 (19.4%)
1	2 (18.2%)	3 (50.0%)	3 (33.3%)	0	2 (66.7%)	10 (27.8%)
2	3 (27.3%)	1 (16.7%)	2 (22.2%)	4 (44.4%)	0	9 (25.0%)
3	2 (18.2%)	2 (33.3%)	3 (33.3%)	3 (33.3%)	0	9 (25.0%)
4	0	0	1 (11.1%)	0	0	1 (2.8%)
5	0	0	0	0	0	0
6	0	0	0	0	0	0
Symptoms score	CWP (n= 11)	Silicosis (n= 6)	MDP (n= 9)	COPD (n= 9)	DDF (n= 3)	Total (n= 36)
0	0	0	0	1 (11.1%)	0	1 (2.8%)
1	7 (63.6%)	3 (50.0%)	0	0	1 (33.3%)	11 (30.6%)
2	1 (9.1%)	2 (33.3%)	0	1 (11.1%)	1 (33.3%)	5 (13.9%)
3	1 (9.1%)	1 (16.7%)	5 (55.6%)	3 (33.3%)	0	9 (25.0%)
4	2 (18.2%)	0	2 (22.2%)	3 (33.3%)	0	6 (16.7%)
5	0	0	2 (22.2%)	0	1 (33.3%)	3 (8.3%)
6	0	0	0	1 (11.1%)	0	1 (2.8%)
Mental state score	CWP (n= 11)	Silicosis (n= 6)	MDP (n= 9)	COPD (n= 9)	DDF (n= 3)	Total (n= 36)
0	4 (36.4%)	1 (16.7%)	0	1 (11.1%)	1 (33.3%)	7 (19.4%)
1	3 (27.3%)	3 (50.0%)	1 (11.1%)	1 (11.1%)	2 (66.7%)	10 (27.8%)
2	2 (18.2%)	2 (33.3%)	1 (11.1%)	1 (11.1%)	0	5 (13.9%)
3	0	0	2 (22.2%)	2 (22.2%)	0	4 (11.1%)
4	1 (9.1%)	0	4 (44.4%)	2 (22.2%)	0	7 (19.4%)
5	1 (9.1%)	0	1 (11.1%)	2 (22.2%)	0	3 (8.3%)
6	0	0	0	0	0	0

Thirty-six subjects completed the CCQ. Two subjects with multiple diagnoses are displayed in each relevant CMDLD diagnosis column, and counted once within the total column.

4.3.5 Smoking Status

Information regarding smoking status and pack-year history was available for 73 and 71 subjects, respectively. This information was collected by questionnaire (MRCQ) or medical chart review, depending on availability. Within this study group, 10% were current smokers, 70% were ex-smokers and 21% were never-smokers. The proportion of ever-smokers and non-smokers was similar across each CMDLD diagnosis (Table 8). Pack-years were calculated and described for 71 subjects, with 68% of subjects having a history of six pack-years or more (Table 9).

As detailed above in section 4.3.3, 80% of subjects reported they were symptomatic. When looking at smoking history and symptoms together, 82% of subjects with a smoking history less than a 5 pack-years had symptoms. In contrast, 78% of those who had smoked more (6+ pack-years) were symptomatic. This suggests there is no correlation between the symptoms reported and smoking history of participants.

Table 8: Smoking status by each sub-category of CMDLD.

	CMDLD Diagnosis					
Smoking category	CWP (n= 25)	Silicosis (n= 10)	MDP (n= 16)	COPD (n= 21)	DDF (n= 4)	Total (n= 73)
Current smoker	2	0	2	2	1	7
Ex-smoker	17	9	10	14	3	51
Never smoker	6	1	4	5	0	15

Seventy-three subjects are included in the table. Three subjects with multiple diagnoses are displayed in each relevant CMDLD diagnosis column, and counted once within the total column.

Table 9: Pack-year smoking history.

Pack-years	Total (n= 71)
0	15
1-5	8
6-25	26
26-50	16
51+	6

4.4 Discussion

Spirometry and symptom questionnaires were employed in the study to better understand the respiratory health of Queenslanders with CMDLD. Both play an important role in the monitoring of lung health over time, as declines in spirometry and an increase in symptoms may indicate progression of the disease. However, given approximately half of the individuals in this study group with a diagnosed CMDLD had normal spirometry, spirometry alone without chest radiograph does not appear to be a sensitive screening tool.

Abnormal spirometry, as determined by the TSANZ guidelines (appendix 4), was observed in over half the group, with most of the abnormalities being obstructive. Other case series conducted internationally have demonstrated similarly high levels of abnormal spirometry (49-52%) in pneumoconiosis patients [44, 45]. Where our study differed was in the pattern of abnormality, with mixed (obstructive and restrictive) impairment being the most common (27-32%). One possible explanation for the high percentage of obstructive abnormalities in our study may be the high levels of cigarette smoking observed within the study group. While the direct link between cigarette smoking and lung disease is already well-established, the additional harm of cigarette smoking in coal industry workers is beginning to be recognized [46]. In our study, there was a high proportion of active (10%) and previous smokers (70%).

Over 80% of the subjects who were assessed for chest symptoms reported their presence (breathlessness, cough, phlegm), suggestive of underlying lung disease. Of greater concern was the fact that breathlessness was more likely to be severe (3 on the mMRC Dyspnoea Scale) than mild or moderate. Unsurprisingly then, of the 36 workers who completed the CCQ, almost 90% reported an impaired quality of life. Similar results were reported in a case series in Turkey, in which less than 10% of 208 pneumoconiosis patients were symptom-free [47].

The TSANZ standards used in our study differ on several accounts to the more established American Thoracic Society (ATS) and European Respiratory Society (ERS) guidelines [40, 48]. Differences in how an abnormality is defined can result in under- or over-diagnosis of disease, leading to different patient outcomes [49]. TSANZ has adopted a broad definition for airflow obstruction by utilising both an absolute (FEV1/FVC <0.7) and LLN cut-off. By using a broad definition, the sensitivity of the test is increased, resulting in a higher detection rate. However, this approach runs the risk of increasing the number of “false positive” referrals by identifying non-pathological changes, such as age and fitness related changes. For this reason, the ATS/ERS guidelines advocate using the LLN cut-off only.

From our data, 59% of the study group who met the definition for airflow obstruction did so based on both the absolute and LLN cut-offs. For those who met the definition on one cut-off only, ten were diagnosed using the absolute cut-off, while three were diagnosed using the LLN cut-off. Of interest, the mean age of subjects who had airflow obstruction on the absolute cut-off was 69 years, while the mean age for those on the LLN cut-off was significantly lower at 52 years. Our data supports the notion that a LLN cut-off, as utilised in the ATS/ERS guidelines, is more effective at detecting airflow obstruction in younger coal industry workers, who would potentially benefit more from earlier detection of changes in lung function. However, it must be noted that assessing the merits of the different guidelines was outside the scope of this study, and further focused-research into the sensitivity and specificity of these difference approaches would be highly informative.

An interesting dilemma was also identified when attempting to classify individuals who met spirometry definition for obstruction (FEV1/FVC <0.7% or FEV1/FVC <LLN) but had FEV1 >80%. There is no provision for this group of individuals in the TSANZ standard, while in the ATS/ERS guidelines they would be labelled as having an obstructive defect. In the reporting for this study, this group has been labelled as having a *borderline* obstructive defect so as to maximise detection of sub-clinical disease. As can be seen from our data, this group accounts for almost 40% of all those identified as having an obstructive defect. The omission of this group, therefore, may lead to missed opportunities for early disease detection and risk mitigation.

This study has a number of limitations. Firstly, the timing of spirometry was not standardised in the study group. Spirometry was performed at different points in relation to the radiological diagnosis of CMDLD. In the vast majority of subjects, spirometry was performed after the radiological diagnosis of CMDLD, including seven subjects who had spirometry performed three (or more) years after the initial diagnosis. This limits the ability of the study to identify useful correlations between radiological and clinical features of CMDLD. A second limitation of the study stems from the small number of subjects who completed the respiratory questionnaires.

Some of the issues considered in this study have been investigated previously in Australian coal workers [50, 51], but to the best of our knowledge, there have been no such studies conducted in the last 25 years. It is hoped that the small case series sheds some light on the levels of abnormal spirometry and symptoms recorded in current cases of CMDLD. Future studies are required to examine the longitudinal effect of coal dust exposure on spirometry and symptoms in Australia. Finally, the re-establishment of a robust health surveillance program, following the Monash and Queensland Parliamentary reviews, should reveal the true prevalence of CMDLD (and its associated spirometry and symptoms) in Queensland [12, 13].

CHAPTER FIVE: OCCUPATIONAL HISTORY

5.1 Background

The likelihood of developing CMDLD is directly related to the duration and intensity of exposure to excessive amounts of coal dust in an occupational setting [30, 52, 53]. Because of this, an understanding of an individual's history, from first exposure to the identification of the disease, is very important when determining CMDLD diagnosis. The purpose of collecting a thorough occupational history is also to exclude alternative explanations for an individual's lung disease. Understanding the type of exposures of an individual is also important, as certain roles may be associated with an increased risk of developing the disease. For example, disease risk may be increased due to heavy exposure or high RCS content of the dust. Specific examples include roof bolting in underground coal mines and drilling in open-cut coal mines, which USA data suggest to be high-risk roles for the development of silicosis because they involve the disturbing/cutting of rock containing silica [54, 55]. Alternatively, roles at the coal face, such as coal extraction, loading and conveyer belt work, may put an individual at increased risk of developing CWP [54].

In Queensland, the DNRME has established a reference document defining Similar Exposure Groups (SEGs) [56]. SEGs group workers into categories based on their dust exposures [57]. By grouping individuals who perform the same or similar roles together, the level of risk can be estimated across an industry. In Queensland, there has been no research into the risk of developing CMDLD in different SEGs. Furthermore, there is no evidence available on whether the high-risk roles identified internationally are of relevance to Queensland workers, given the differences in mining techniques, coal seam characteristics, and dust controls. For this reason, an occupational history questionnaire was designed to capture the histories of workers recently diagnosed with a CMDLD. The aim of this component of the project was to collect a detailed level of information to help provide an understanding of the occupational histories of workers with a positive CMDLD diagnosis.

5.2 Methods

Occupational information was obtained in two ways: a review of medical charts by research staff and completion of a questionnaire by the subjects. For all subjects, data was collected from medical charts. The completeness of data collected from medical charts varied greatly but, at a minimum, information confirming the subject had worked in the Queensland coal industry was required. Additional information, such as years worked and type of mine, was available from the medical charts for most subjects (75/79). An occupational history questionnaire, designed specifically for use in this study, was utilised for an in-depth collection of occupational history, with informed consent.

The occupational history questionnaire was created in Qualtrics Survey Software (Qualtrics, USA, 2018) [58] and delivered electronically (Appendix 5). The questionnaire comprised a maximum of 181 questions, dependent on a subject's answers. The questionnaire was designed to collect information on a subject's complete work history, with a focus on coal mining, but also screened for other histories of relevance to lung disease, including hard rock mining, quarry work, agriculture and bird keeping. Coal industry information collected included years worked, mine sites, roles (SEGs), personal protective equipment (PPE) use, dust controls, and education on dust safety.

The SEG codes utilised in this study were those defined by the DNRME in 2017 [56]. These are categorised into underground roles, open-cut roles and coal handling preparation plant roles (CHPP).

5.3 Results

5.3.1 Occupational Analysis of the Study Group (Retrospective Data)

Each subject included in this series had an occupational history that included work in the Queensland coal industry (n= 79). Further occupational information was available in varying degrees of completeness for the majority of subjects (n= 75). No additional occupational information was available for four subjects.

As at 1st January 2018, 30 of the 79 subjects were known to be actively working in the Queensland coal industry; 42 were retired or former coal industry workers; and occupational status was unknown for the remaining seven. The mean tenure in the coal mining industry was 26.2 years (n= 74, range: 6-45). The earliest and most recent years when subjects reported having commenced work in the coal industry were 1955 and 2008, respectively (data available for 69 subjects). Nineteen of these subjects reported first working in the coal mining industry between 2000 and 2008.

Medical charts often contained basic information, such as years worked in the coal industry (n= 68) and type of mine (n= 75). The higher detail information, such as duration of work within specific SEGs, was collected only via the questionnaire (n= 36). The majority (74%) of subjects had only worked in the Queensland coal industry, without any interstate or overseas mining history. The remainder had spent a portion of their careers working in coal mining either interstate (11%) or overseas (15%). A period of employment in mining other than coal mining, including hard rock mining (n= 17) and/or quarry work (n= 4), was reported by 27% of the subjects. The 17 subjects who had worked in hard rock mining had done so for a mean of 7.5 years, compared to their mean tenure in coal mining of 20.2 years. The four subjects who had worked in quarries had done so for a mean of 8.3 years, compared to their mean tenure in coal mining of 18.5 years. For all subjects with employment history in quarries or hard rock mining, their employment in the Queensland coal industry was attributed to their CMDLD diagnosis, with 85% having a diagnosis primarily related to coal dust (CWP or MDP). In all cases where workers had been employed outside of Queensland, or outside of the coal industry, their work in Queensland was determined to significantly attribute to their CMDLD by their treating specialist.

Forty-four per cent of the subjects had worked only in underground coal mining and these men had a mean tenure of 26.5 years (range: 6-43). A history of only open-cut coal mining was reported by 27%, with a mean tenure of 23.8 years (range: 10-43). Work in both underground and open-cut coal mining was reported by 29% of subjects, with a mean tenure of 28 years (range: 10-45). There were two subjects who had never worked in a coal mine but were employed in coal ports where they were exposed to coal dust. For the purposes of this study, these two subjects were classified as open-cut workers because the subjects reported completing tasks similar to those performed at an open-cut mine. The period during which most of the subjects worked occurred after the year 2000 (Figure 4).

As stated, within our study group, 44% of subjects had worked in underground mines only, 27% had worked in open-cut mines only, and 29% had worked in both underground and open-cut mines (Table 10). Within the diagnoses of CWP, MDP and silicosis, underground-only work was reported by 50% or more of subjects (Table 10). In contrast, subjects with DDF and COPD, most commonly reported they had worked in open-cut mines only.

Table 10: History of work across each mine type, number (%) and total mean tenure (range) for subjects within each CMDLD diagnosis.

	CMDLD diagnosis					
Coal mine type	CWP (n= 26)	MDP (n= 16)	Silicosis (n= 10)	DDF (n= 5)	COPD (n= 22)	Total (n= 75)
Underground only	14 (53.8%)	9 (56.3%)	5 (50.0%)	1 (20.0%)	5 (22.7%)	33 (44.0%)
Open-cut only	4 (15.3%)	2 (12.5%)	4 (40.0%)	3 (60.0%)	9 (40.9%)	20 (26.7%)
Both	8 (30.7%)	5 (31.3%)	1 (10.0%)	1 (20.0%)	8 (36.4%)	22 (29.3%)
Mean tenure (range)	26.1 (6-43)	24.7 (10-39)	26.1 (10-42)	20.6 (10-32)	27.6 (11-45)	26.2 (6-45)

Seventy-five subjects are included in the table. Four subjects with multiple diagnoses are displayed in each relevant CMDLD diagnosis column, and counted once within the total column.

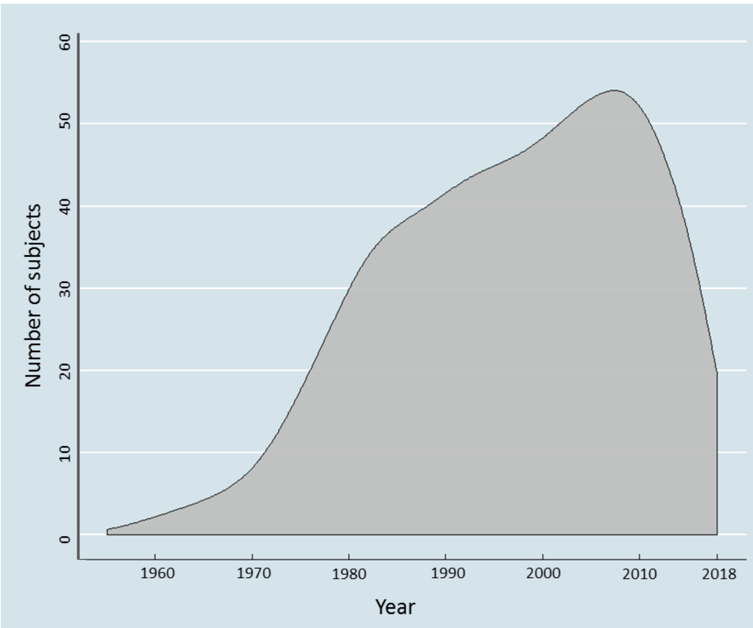


Figure 4: Density plot of the years during which the study group worked in the coal mining industry (n= 68).

5.3.2 Occupational Analysis of the Study Group (Questionnaire Data)

There were 36 men who completed the occupational questionnaire, thus providing additional, in-depth information on occupational history. This group of men reported working in the coal mining industry for a cumulative total of 918 years (Table 11). Eighteen individuals reported predominately working in SEGs categorised as underground, 17 reported working predominantly in open-cut SEGs and one in CHPP (Table 11). The specific

SEG in which the subjects spent the most time was Development Production (QCU002), with 129 years of work by 19 subjects. Of the top ten most worked SEGs, four were within the underground category and six were in the open-cut category (Table 12). The subjects worked across a mean of eight different SEGs during their careers.

Additional available data, such as mine site, were excluded from this report because the small numbers involved in the questionnaire meant workers could potentially be identified.

Table 11: Number of subjects (%) who reported predominant work history within each SEG category and total years (%) spent within that category.

SEG category	Predominant history in SEG category (n= 36)	Total years (%)
Underground	18 (50.0%)	441 (48.0%)
Open-cut	17 (47.2%)	444 (48.4%)
CHPP	1 (2.8%)	33 (3.6%)

Table 12: The top ten SEGs that subjects (n= 36) reported having spent the most time within during their coal mining careers, ranked by years, highest to lowest.

Rank	SEG (DNRME code), description	SEG category	Total years (*n* subjects)
1	**Development Production (QCU002)**, Employees and contractors operating as a continuous miner; operating a shuttle car or ram car; undertaking roof and rib bolting; hanging hoses, handling cables, hanging vent tubes, performing belt extensions, hanging brattice.	Underground	129 (19)
2	**Dragline (QCS017),** Employees and contractors operating or supporting dragline operations.	Open-cut	86 (7)
3	**Pre-strip and overburden removal (QCS001),** Employees and contractors working in pre-strip areas of the mine and operating equipment (e.g. haul trucks, loaders, dozers, graders and excavators).	Open-cut	76 (14)
4	**Blast crew (QCS007),** Employees and contractors undertaking blasting and shot firing duties.	Open-cut	65 (5)
5	**Coal removal (QCS002),** Employees and contractors involved in the removal of product	Open-cut	56 (12)

	coal (e.g. digger/shovel, dump trucks).		
6	**Underground maintenance (QCU003),** Employees and contractors performing mechanical maintenance services underground; performing electrical maintenance underground; undertaking mechanical repairs and vehicle servicing underground.	Underground	53 (14)
7	**Production dozing (QCS018),** Employees and contractors operating in production dozing operations.	Open-cut	49 (10)
8	**Longwall production (QCU001),** Employees and contractors who operate or rotate through the following tasks: operating shearer (tailgate or maingate); operating maingate drive; operating chocks / shields.	Underground	40 (8)
9	**Workshop (QCS014),** Employees and contractors undertaking electrical and mechanical maintenance and services predominantly in the workshop.	Open-cut	40 (4)
10	**Returns (QCU020),** Employees and contractors routinely undertaking maintenance, construction, service recovery, secondary support, stone dusting and services extension / retractions activities in return airways.	Underground	30 (10)

5.4 Discussion

The main findings in regards to occupational history included: all subjects had worked in Queensland coal mining and three quarters only in Queensland; a majority of the work occurred from 2000 onwards; and about one-half of the subjects had only worked underground and one quarter only above ground. In addition, CWP was more common in underground workers, silicosis was equally common in underground and open-cut workers, and COPD less common in underground workers than workers who had worked in open-cut mines only or in open-cut and underground mines.

Some of the subjects (27%) worked in other high-dust industries in addition to coal mining and it is likely some were exposed to RCS during that employment. However, within our methodology we were careful to ensure only individuals with disease primarily related to coal dust exposure were included. This is evidenced by the differences in tenure between coal work and non-coal work. Further, we also believe our stringent inclusion criteria is evidenced by the proportions of diagnoses observed; for example by CWP being the most common CMDLD, and by many of the silicosis subjects having little or no work exposure outside of coal.

Furthermore, about one quarter of the subjects reported starting work between 2000 and 2008. Providing the occupational histories are reasonably accurate in terms of approximate dates of employment, the results strongly suggest that in the last two decades dust levels have not been controlled effectively, as many subjects have developed CMDLD despite only working during this period. That is, the CMDLD cases included in this study are not only due to exposures from many decades ago but also exposure from more recent years.

Without additional information about the at-risk population, and because not all affected coal industry workers were included in the study group, these results do not provide any direct insight into the risk of dust-related disease in underground miners compared to open-cut workers. However, they strongly indicate that exposures in open-cut work are high enough to result in CMDLD. This is a somewhat surprising finding, given that, typically, the focus on dust exposures is with underground work, because of the expectation that dust exposures would be much higher there than at the surface. This emphasises the importance of measuring dust levels and instituting appropriate control measures in all aspects of coal mining work. The results also identified SEGs that were most commonly worked by the affected coal industry workers, but without having all the cases and without having information on employment numbers in each SEG, it is not possible to confidently identify the SEGs which provide the highest risk to workers of developing CMDLD. Further, given the high number of SEGs subjects worked across (mean of 8) it is not possible to correlate work within a specific SEG to the development of CMDLD.

The mean tenure in the study group was about 26 years, but some affected workers had been in the industry for as little as six years. This emphasises the fact that CMDLD is not necessarily a disease of old men with decades of work in coal mining. Again, this demonstrates the importance of having adequate dust control measures in place at all times, inclusive of personal exposure management.

As previously mentioned, it was not within the scope of this study to investigate the occupational dust exposures of the subjects. It must also be noted, that although we collected information on the history of PPE use within the occupational questionnaire, no meaningful conclusions on PPE use within subjects could be drawn. The primary reasons for this were the small number of subjects and the inability to validate claims around PPE use, or that PPE if used, was done so properly. Future research investigating perceptions of risk of workers around certain roles and PPE use would be of value to the medical and mining industries. It is hypothesised that diligence of PPE use is variable between workers depending on the perceived dust level to which that worker is exposed. For example, although dust levels may be lower within air-conditioned cabins than for those working nearby drilling or cutting of coal, those who are exposed to higher levels of dust may be more likely to use respiratory PPE. Variable use of PPE, depending on perceived dust levels, may explain why a worker who primarily worked in a role, perceived to be of minimal dust exposure, could inhale enough mine dust to cause disease. Further, no research has been conducted to date on the dust exposures of workers wearing PPE, but rather has focused exclusively on the dust levels within the working environment.

Many of the main limitations of the study in terms of the occupational aspects have already been referred to. The cases do not represent all cases of CMDLD in current and retired Queensland coal workers. Nor are they likely to represent a random sample of such cases, although it is not known the extent to which they may not be representative. Occupational information was available for all the subjects included in the study, but only about half provided detailed information by completing the questionnaire component. The extent to which these limitations, the representativeness of cases and the completeness of information affect the validity of the study results is not known. For this reason, the interpretation of the data has been qualified. It must also be re-iterated that this study utilised SEGs as defined by the DNRME in 2017, and that the definitions of SEGs may have changed over time and likely differ between jurisdictions.

Despite the limitations just described, the study provides some important insights into the issue of CMDLD in the Queensland coal mining industry. At the least, the results show that dust exposure over the last two decades has resulted in workers, some with exposures of 10 years or less, developing clinically relevant CMDLD. Also, that above ground work, not just underground work, can generate dust exposures high enough to result in cases of CMDLD.

CHAPTER SIX: MULTI-DISCIPLINARY ANALYSIS

6.1 Background

The previous chapters report results of the study group combined, or categorized by diagnosis. In this chapter, data from standalone chapters is analysed beyond this level, in a multi-disciplinary fashion. The specific aim of each analysis undertaken is detailed within the relevant section below.

6.2 Methods

The data utilised to compare across disciplines is as described in previous chapters, and summarised in Table 13. Analyses were performed using R software [59].

Table 13: Key variables summary table.

Variable	Results
Demographics	
Mean age in years, (range)	58.9 (35-90)
Male sex, n (%)	79 (100%)
Tenure	
Mean tenure in coal mining, years (range)	26.2 (6-45)
Mine type	
Underground only, n (%)	33/75 (44.0%)
Open-cut only, n (%)	20/75 (26.7%)
Both, n (%)	22/75 (29.3%)
Smoking history, n (%)	
Never-smokers, n (%)	15/73 (20.6%)
Ever-smokers, n (%)	58/73 (79.5%)
Mean pack years (range)	27.1 (1-138)
Spirometry	
Mean FEV1% (range)	81.3 (17.4-127.4)
Mean FVC% (range)	92.3 (42-141.2)
Mean FEV1/FVC (range)	0.7 (0.2-0.9)
Clinical	
Breathlessness, n (%)	26/36 (72.2%)
Symptomatic (cough/phlegm/wheeze), n (%)	29/36 (80.6%)
Radiological grade	
Mean ILO Grade (range)	1/1 (0/0-3/3)
Grade 1 ILO, n	45
Grade 2 ILO, n	15
Grade 3 ILO, n	4
Mean ICOERD nodular grade (range)	5.5 (0-16)

6.3 Results

6.3.1 Disease Severity as Assessed on Radiology and Spirometry

Correlation of disease severity, as assessed by radiology (ILO and ICOERD) and spirometry (FEV1% and FVC%), was undertaken to establish whether any relationship was seen between these measures. There were 54 subjects where both chest radiograph and spirometry were available for comparison. Similarly, there were 51 subjects where both HRCT and spirometry were available. No relationship was observed in the study group between radiological severity, either on chest radiograph or HRCT, and spirometry ($p > 0.05$ in all comparisons) (Appendix 6).

6.3.2 Radiological Severity and Tenure in Coal Mining

Correlation of radiology grades of severity (ILO and ICOERD) and tenure in the coal mining industry (years) was undertaken to establish whether there was any relationship between these variables. There were 52 subjects for whom both tenure and chest radiograph data were available. Similarly, there were 51 subjects for whom both HRCT and tenure data were available. These data were used to construct the graphs in Figure 5. No relationship was observed in our study group between radiological severity, either on chest radiograph or HRCT, and tenure in the coal industry ($p > 0.05$) (Figure 5).

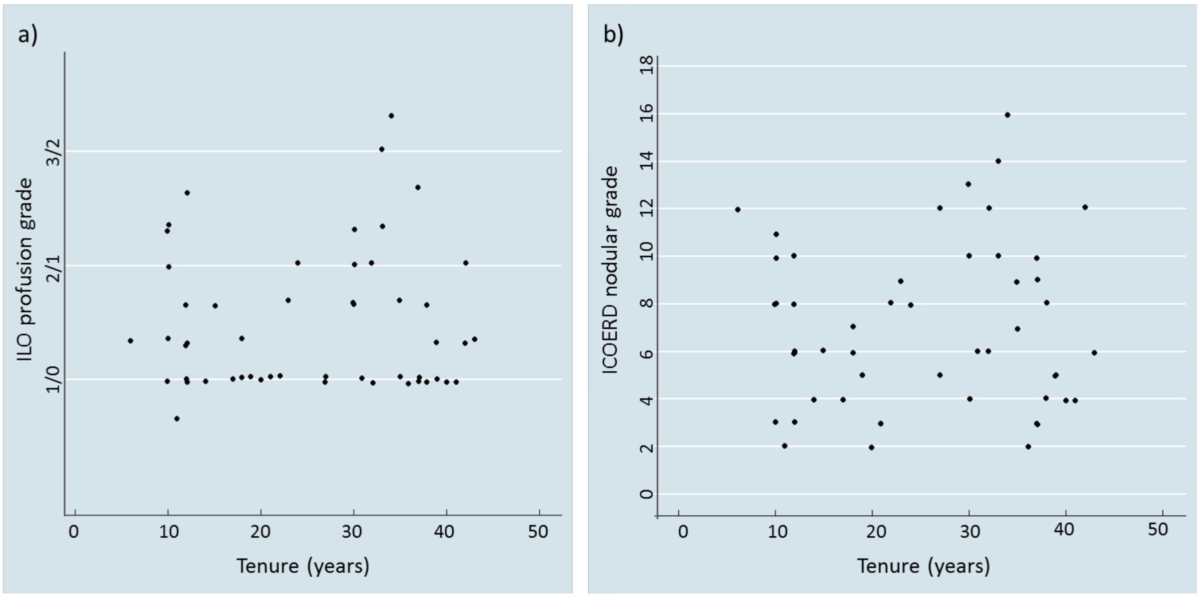


Figure 5: Disease severity assessed by radiological grades and coal mining industry tenure. Correlation between ILO profusion grade on chest radiograph (5a) and ICOERD nodular grade on chest HRCT (5b) plotted against tenure in the coal mining industry (years) for subjects with a nodular CMDLD.

6.3.3 Radiological Severity and Coal Mine Type

Correlation of radiological severity (ILO and ICOERD) and the type of coal mine worked in (underground only, open-cut only, or both) was undertaken to establish whether the severity of disease could be associated with the history of working in certain coal mine type(s). There were 51 subjects for whom both mine type and chest radiograph data were available. Similarly, there were 50 subjects for whom both mine type and chest HRCT data were available. These data were used to construct the graphs in Figure 6. No relationship was present in the study group between radiological severity, either on chest radiograph or HRCT, and the type of coal mine worked in (p >0.05) (Figure 6).

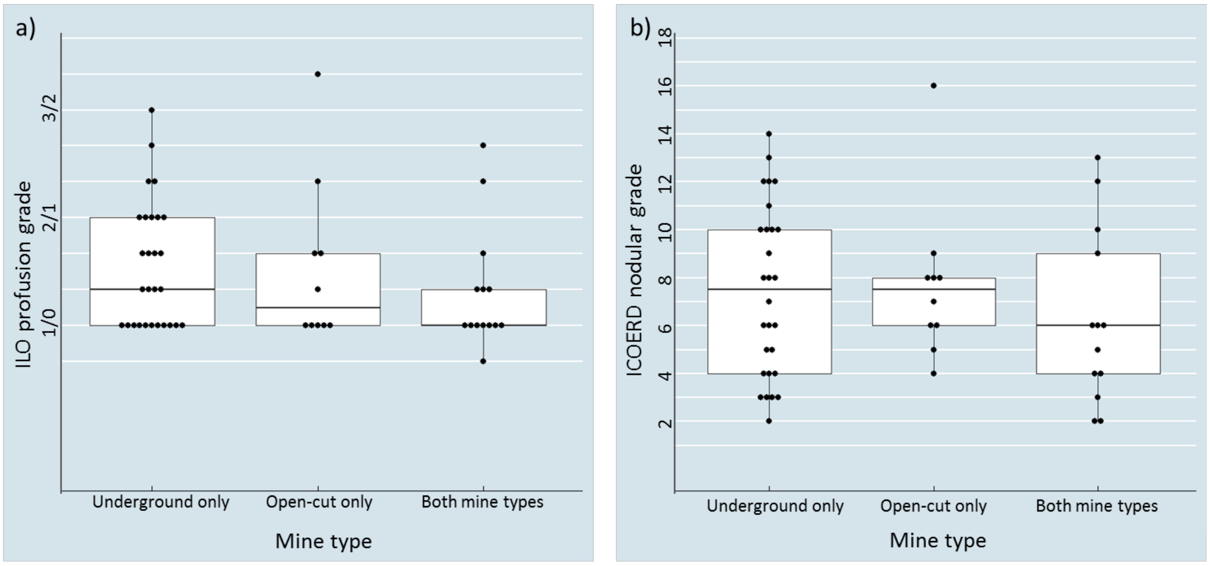


Figure 6: Severity of disease assessed by radiological grades and coal mine type**.** Radiological severity, ILO profusion grade on chest radiograph (6a) and ICOERD nodular grade on chest HRCT (6b), plotted against coal mine types. For interpretation of box and whisker plots, see Appendix 3.

6.3.4 Disease Severity as Assessed on Spirometry, Coal Mine Type and Tenure

Correlation of spirometry values (FEV1%, FVC% and FEV1/FVC) and occupational history (tenure and coal mine type) was undertaken to investigate whether any relationships existed. There were 73 subjects for whom both spirometry and tenure data were available. Similarly, there were 72 subjects for whom both spirometry and mine type data were available. These data were used to construct the graphs in Figure 7. No relationship was observed in our study group between spirometry values and occupational tenure or coal mine type (p >0.05) (Figure 7, data shown for FEV1/FVC only). Analyses were also conducted on FEV1% and FVC% without any relationship being observed (data not shown).

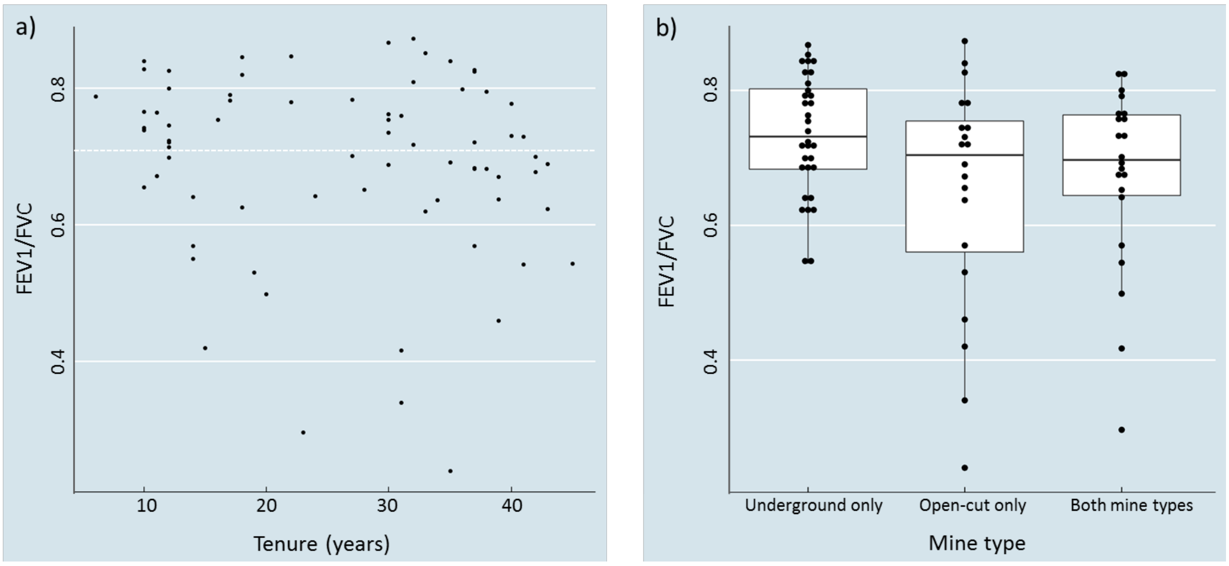


Figure 7: Relationship between spirometry (FEV1/FVC) and two occupational history factors; tenure in coal mining (7a) and coal mine type (7b). For interpretation of box and whisker plots, see Appendix 3.

6.3.5 Breathlessness, Smoking History and Radiological Severity

Within this study, odds ratios (OR) were calculated to determine whether there was an association between breathlessness and either smoking history or radiological severity. These calculations were performed using the mMRC Dyspnoea Scale, which was collected during the questionnaire component of this study, thereby limiting the sample size to those who completed the questionnaire (n= 36).

An OR was calculated to determine whether there was an association between smoking history and severe breathlessness (mMRC grade ≥2). This analysis showed no significant association between smoking history and breathlessness, suggesting that individuals were no more likely to report severe breathlessness if they were past or present smokers (≥5 pack year history of smoking) compared to those with little to no smoking history (<5 pack years) (OR= 1.31 [95% confidence interval (CI): 0.31-5.53]) (p= 0.71) (Table 14).

The OR was also calculated to determine whether advanced radiological disease (ILO profusion grade ≥2/1 or presence of PMF) were associated with severe breathlessness (mMRC grade ≥2). This analysis showed no significant association between advanced radiological disease and breathlessness (OR= 1.00 [95% CI: 0.25-4.00]) (p= 1.00) (Table 14).

Table 14: Breathlessness in relation to smoking and ILO profusion grade.

Independent variable	n	OR	95% CI		p-value
			lower	upper	
Smoking	36	1.31	0.31	5.53	0.71
ILO grade	36	1.00	0.25	4.00	1.00

6.4 Discussion

Examination of the extent of relationships between various variables reviewed in this study did not identify any correlations of note. Some of these results are surprising. The main surprise was the lack of a positive association between smoking history and breathlessness, as this would typically be expected, based on the fact that smoking is known to adversely affect respiratory function. Given that the point estimate of the odds ratio was above one (as expected), the problem might well have been a lack of precision of the estimates, or errors in the measurements, as considered below.

Tenure in the mining industry and the type of work (underground or open-cut) are rough proxy measures for cumulative dust exposure, which is expected to be the key determinant of the probability and severity of the functional and radiological severity of CMDLD. Therefore, it might be expected that these measures would be associated with the radiological severity as measured by chest radiograph or HRCT, or the functional severity as measured by spirometry. The fact that no association was demonstrated may well be due primarily to the low power of the study (due to the small number of subjects that could be included in the analysis), the resulting imprecision making it difficult to identify underlying relationships that might exist. There may also have been some inaccuracy in the reporting of symptoms and smoking history by the subjects. The radiological measures are expected to have good accuracy, as are the spirometry measures, although the scope for problems with measurement technique and reporting, as mentioned in Chapter 4, means there can be less confidence with the spirometry results. Since such errors in one type of variable (work history and spirometry) are likely to be independent of the values in other variables, the effect of these issues (lack of power and measurement error) is likely to make it harder to identify any relationship that might exist between variables.

For similar reasons, the lack of identification of expected positive relationships between radiological severity and either spirometry or symptoms of breathlessness might well be due to low power and/or measurement error. However, low power is less likely to be an explanation for the radiology-breathlessness finding, since the estimated odds ratio was 1.0. Another contributor to the lack of an identified relationship between radiological severity and measures of respiratory symptoms or function may be that radiological signs are not a good indicator for an individual's degree of functional respiratory impairment.

As with the occupational history data, many of the analyses presented here did not include all subjects, and the subjects who were included may well not have been representative of all cases. However, these selection issues should not have affected the analyses presented in this chapter because the involvement or lack of involvement of a subject is not likely to have been influenced by any of the particular relationships examined in this section.

In summary, no correlations of note between the variables of interest were observed. The low power of the study, and to a lesser extent the potential for measurement error, means this lack of identified correlations may not adequately represent the true relationships between at least some of these variables. Continued research, including re-analysis of these relationships would be of the utmost interest, as further CMDLD cases are identified and additional data points become available.

CHAPTER SEVEN: DISCUSSION

7.1 Summary

In Queensland, CMDLDs have been under-diagnosed since 1984, leading to a lack of awareness within both the mining and medical industries. In Queensland, CWP was believed to be eradicated for decades until re-identification of this disease in 2015. The recent independent inquiries (the Monash and Queensland Parliamentary reviews) have revealed that the status of CMDLD in Queensland is not known and that for years the CMWHS in place has had inherent flaws, leading to these diseases going undetected.

To summarise the key findings of this project, 79 current or former Queensland coal workers with a diagnosis of CMDLD were the focus of this report:

- All instances of CMDLD were formally confirmed through a review process
- Clinical diagnoses included CWP (n= 27), MDP (n= 18), silicosis (n= 11), DDF (n= 5) and COPD (n= 22)
- Ages ranged from 35 to 90, with a mean of 59 years
- 30% of subjects had radiologically advanced disease, including six with PMF
- 47% of subjects had normal spirometry, compared to 53% with abnormal spirometry
- 26/36 subjects reported breathlessness as a respiratory symptom
- 80% of subjects were ever-smokers, with a mean pack-year history of 27 (range: 1-138)
- 38% of subjects were actively working in the Queensland coal industry; 53% of subjects were known to be retired or former coal workers; and data was missing for seven subjects
- The mean tenure in the coal mining industry was 26 years (range: 6-45 years)
- 27% of subjects had no experience in underground coal mines, inclusive of two subjects who had worked in coal ports only
- 28% of subjects started work in coal mining in 2000 or onwards
- 26% of subjects had worked in coal mines outside of Queensland, either interstate or overseas, as well as in Queensland
- 27% of the subjects had worked in hard rock mining (n= 17) and/or quarry work (n= 4), as well as in the coal industry.

International research has shown a long occupational history of coal mine dust exposure is the most important risk factor for the development of the CMDLDs which we researched here. The incurable nature of CMDLD means prevention is important. Once the disease process has commenced, progression can be slowed or stopped by minimising continued dust exposure. This means that early diagnosis is very important to ensure workers with early disease are detected and appropriate occupational and general measures put in place.

7.2 Limitations

The case series did not include all affected current and retired Queensland coal mine workers. The most common type of CMDLD in the study group was the nodular pneumoconiosis CWP. This is unsurprising given this case series was comprised of individuals with predominant occupational histories in the coal industry. Furthermore, the nodular forms of disease are easiest to diagnose and attribute to coal mine dust because they are specifically related to dust exposure. This differs from COPD, which may be wholly or partially attributed to cigarette smoking. In this study we were careful to include COPD subjects only if there disease was clearly attributed to their work in the coal industry. Thus, selection bias for the nodular forms of CMDLD probably occurred.

Another major limitation of this project relates to the delayed diagnosis of CMDLD. Improvements to the CMWHS commenced in 2016 in Queensland. Therefore, workers in this study have probably received a late diagnosis of CMDLD. The absence of a co-ordinated screening program for CMDLD in Queensland produced some limitations in the availability of data for the project, including the lack of health screening medical records and images that would have otherwise allowed some determination of when a worker's lung disease developed. Combined with the long latency of CMDLD, this study was unable to establish which occupational hazards and exposures led to the subjects' development of CMDLD. Furthermore, this study is a case series only and does not include data from healthy coal industry workers that would be needed to identify potential occupational risk factors. Finally, given that the mean tenure in the coal industry for the study group was 26 years, there is clearly a considerable risk of error in the recall of early occupational exposures by subjects completing the questionnaire.

7.3 Conclusion

This study provides evidence that CMDLD exists in the Queensland coal industry and provides the first medical insight into these diseases in Queensland in over three decades. It is hoped the findings of this study lead to an increased awareness of these diseases and their current status in Queensland; continued improvement in the control of dust exposures; and high-quality disease surveillance.

7.4 Future Directions and Recommended Research Areas

The prevalence and incidence of CMDLD in Queensland remains unknown. For many years there was no adequate health screening scheme in place in Queensland, meaning prevalence and incidence could not be determined. With the recent changes to the CMWHS, data that could provide this information is becoming available. The delayed diagnosis for many of the subjects in the study, in most cases after many years of occupational dust exposure, means that conclusions could not be made in regards to identification of specific risk factors. The collection of on-going data should help rectify this, although the necessary information will require data collection over many years. As further data becomes available additional areas which could be investigated include; spirometry and the sensitivity/specificity of different interpretation algorithms; genetics and the role this plays in disease susceptibility; SEGs and the evidence-base for categorising workers in this manner; the influence perceived dust levels within a certain role/area have on PPE use; and the difference between environmental dust levels and a worker's dust exposure when using PPE. Finally, this study reviewed subjects at one point in time. In future, longitudinal studies of subjects would be of interest to determine disease and symptom progression.

GLOSSARY

ACARP	The Australian Coal Association Research Program
ATS	American Thoracic Society
CCQ	Clinical COPD Questionnaire
CHPP	Coal Handling Preparation Plant
CI	Confidence Interval
CMDLD	Coal Mine Dust Lung Disease
CMWHS	Coal Mine Worker's Health Scheme
COPD	Chronic Obstructive Pulmonary Disease
CWP	Coal Workers' Pneumoconiosis
DDF	Dust-Related Diffuse Fibrosis
DNRME	Department of Natural Resources, Mines and Energy
ERS	European Respiratory Society
FEV	Forced Expiratory Volume
FEV1	Forced Expiratory Volume over 1 second
FVC	Forced Vital Capacity
GGO	Ground Glass Opacities
HRCT	High-Resolution Computed Tomography
ICOERD	International Classification of HRCT for Occupational and Environmental
ILO	International Labour Office
LLN	Lower Limit of Normal
MDP	Mixed Dust Pneumoconiosis
mMRC	Modified Medical Research Council
MRCQ	Medical Research Council Questionnaire
OEL	Occupational Exposure Limit
OR	Odds Ratio
PB	Pleural Linear Opacities
PMF	Progressive Massive Fibrosis
PPE	Personal Protective Equipment
RCS	Respirable Crystalline Silica
SC	Subpleural Curvilinear opacities
SEG	Similar Exposure Group
TSANZ	The Thoracic Society of Australia and New Zealand
USA	United States of America
WHO	World Health Organisation

APPENDICES

Appendix 1 - Chest Radiograph Grading System

The International Labour Office (ILO) Classification System of Radiographs of Pneumoconioses is the step-by-step method and criteria for describing and grading a chest radiograph for pneumoconiosis [34]. The focus of this system is to describe the type and profusion of opacities (Figure 8). The steps taken in assessing a chest radiograph using the ILO classification system are described below.

Image quality

The first step in assessing a chest radiograph is for image quality, with quality grades from 1 (high quality) to 3 (low quality), in addition to defining the chest radiograph as un-reportable (Figure 9, section 1).

Opacities: type and profusion

Second, the chest radiograph is assessed for abnormalities, specifically opacities, within the lung (Figure 9, 2A). Opacities are described based on their shape and size, location and profusion. The shape of opacities are described as either rounded or irregular, and sizes range from <1.5 mm to 10 mm. In total there are six different opacity types; rounded opacity types are p (<1.5 mm), q (1.5-3 mm) and r (3-10 mm) and irregular opacities are types s (<1.5 mm), t (1.5-3 mm) and u (3-10 mm). The number of opacities seen on a chest radiograph (profusion) is graded from 0 to 3 (Figure 8 and Figure 9, 2b). The profusion of opacities is assessed for each region of the lungs by dividing the lungs into three zones (upper, mid and lower) on both the right and left sides (Figure 8). The overall profusion of a chest radiograph is classified based on which ILO standard chest radiograph most closely matches the subject's film, with the first number reflecting the predominant profusion grade and a second number given if the radiographic profusion is between two standard chest radiographs. For example, an ILO grade of 1/0 indicates the individual has slightly fewer nodules on their CXR compared to the standard 1/1 film.

Large opacities (progressive massive fibrosis), defined as an opacity over 10 mm, are described as either A (10-50 mm), B (>50 mm but not exceeding equivalent area of the right upper lung zone), or C (the longest diameter exceeds the equivalent area of the right upper lung zone) (Figure 9, 2C.)

Pleural abnormalities

Third, the bases of the lung (pleura) are assessed for thickening, which is of relevance in identifying asbestos-related disease (Figure 9, 3C and 3D).

Other abnormalities

Finally, any other abnormalities are recorded, such as lymph node calcification and emphysema (Figure 10, 4B). Additional abnormalities, unrelated to occupational lung disease, such as bone fractures are also recorded (Figure 10, 4C).

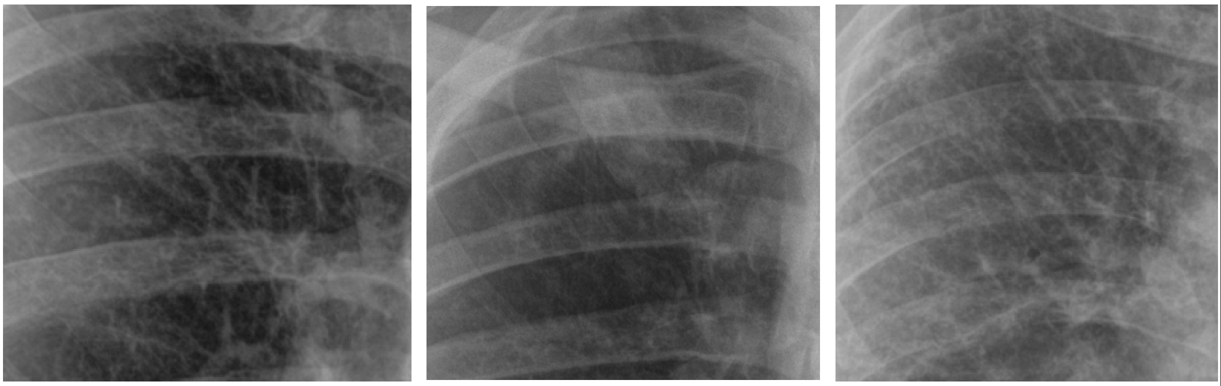
Grade 1 (1/0, 1/1, 1/2)	**Grade 2** (2/1, 2/2, 2/3)	**Grade 3** (3/2, 3/3, 3/+)
		
Small number of opacities which do not distort the normal vascular structures	Moderate number of opacities which partially obscure normal vascular structure	Large number of opacities with complete destruction of the normal vascular structures

Figure 8: Profusion grades within the ILO classification system range from 1 to 3. Three chest radiographs from subjects within this study are provided as representative images (profusion grade underlined).

1. IMAGE QUALITY

1 2 3 U/R

(If not Grade 1, mark all boxes that apply)

☐ Overexposed (dark) ☐ Improper position ☐ Underinflation

☐ Underexposed (light) ☐ Poor contrast ☐ Mottle

☐ Artifacts ☐ Poor processing ☐ Other (please specify)

2A. ANY CLASSIFIABLE PARENCHYMAL ABNORMALITIES? YES ☐ Complete Sections 2B and 2C NO ☐ Proceed to Section 3A

2B. SMALL OPACITIES

a. SHAPE/SIZE

PRIMARY		SECONDARY		b. ZONES	R	L	c. PROFUSION		
							0/-	0/0	0/1
p	s	p	s	UPPER	☐	☐	1/0	1/1	1/2
q	t	q	t	MIDDLE	☐	☐	2/1	2/2	2/3
r	u	r	u	LOWER	☐	☐	3/2	3/3	3/+

2C. LARGE OPACITIES

SIZE O A B C Proceed to Section 3A

3A. ANY CLASSIFIABLE PLEURAL ABNORMALITIES? YES ☐ Complete Sections 3B, 3C NO ☐ Proceed to Section 4A

3B. PLEURAL PLAQUES *(mark site, calcification, extent, and width)*

Chest wall	Site	Calcification
In profile	O R L	O R L
Face on	O R L	O R L
Diaphragm	O R L	O R L
Other site(s)	O R L	O R L

Extent (chest wall; combined for in profile and face on)
Up to 1/4 of lateral chest wall = 1
1/4 to 1/2 of lateral chest wall = 2
> 1/2 of lateral chest wall = 3

O R: 1 2 3 O L: 1 2 3

Width (in profile only)
(3mm minimum width required)
3 to 5 mm = a
5 to 10 mm = b
> 10 mm = c

O R: a b c O L: a b c

3C. COSTOPHRENIC ANGLE OBLITERATION R L Proceed to Section 3D NO ☐ Proceed to Section 4A

3D. DIFFUSE PLEURAL THICKENING *(mark site, calcification, extent, and width)*

Chest wall	Site	Calcification
In profile	O R L	O R L
Face on	O R L	O R L

Extent (chest wall; combined for in profile and face on)
Up to 1/4 of lateral chest wall = 1
1/4 to 1/2 of lateral chest wall = 2
> 1/2 of lateral chest wall = 3

O R: 1 2 3 O L: 1 2 3

Width (in profile only)
(3mm minimum width required)
3 to 5 mm = a
5 to 10 mm = b
> 10 mm = c

O R: a b c O L: a b c

4A. ANY OTHER ABNORMALITIES? YES ☐ Complete Sections 4B, 4C, 4D, 4E NO ☐ Complete physician info and sign form.

5. PHYSICIAN'S Social Security Number* ☐☐☐ - ☐☐ - ☐☐☐☐

Full SSN is optional, last 4 digits are required.

READER'S INITIALS ☐☐☐

DATE OF READING (mm-dd-yyyy) ☐☐ - ☐☐ - ☐☐☐☐

SIGNATURE

PRINTED NAME (LAST, FIRST MIDDLE)

STREET ADDRESS CITY STATE ZIP CODE

Figure 9: Standard form (page 1) used for grading a chest radiograph for pneumoconiosis within the ILO Classification System of Radiographs of Pneumoconioses.

4B. OTHER SYMBOLS (OBLIGATORY)

aa	at	ax	bu	ca	cg	cn	co	cp	cv	di	ef	em	es	fr	hi	ho	id	ih	kl	me	pa	pb	pi	px	ra	rp	tb
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

- aa atherosclerotic aorta
- at significant apical pleural thickening
- ax coalescence of small opacities - with margins of the small opacities remaining visible, whereas a large opacity demonstrates a homogeneous opaque appearance - may be recorded either in the presence or in the absence of large opacities
- bu bulla(e)
- ca cancer, thoracic malignancies excluding mesothelioma
- cg calcified non-pneumoconiotic nodules (e.g. granuloma) or nodes
- cn calcification in small pneumoconiotic opacities
- co abnormality of cardiac size or shape
- cp cor pulmonale
- cv cavity
- di marked distortion of an intrathoracic structure
- ef pleural effusion
- em emphysema
- es eggshell calcification of hilar or mediastinal lymph nodes
- fr fractured rib(s) (acute or healed)
- hi enlargement of non-calcified hilar or mediastinal lymph nodes
- ho honeycomb lung
- id ill-defined diaphragm border - should be recorded only if more than one-third of one hemidiaphragm is affected
- ih ill-defined heart border - should be recorded only if the length of the heart border affected, whether on the right or on the left side, is more than one-third of the length of the left heart border
- kl septal (Kerley) lines
- me mesothelioma
- pa plate atelectasis
- pb parenchymal bands - significant parenchymal fibrotic stands in continuity with the pleura
- pi pleural thickening of an interlobar fissure
- px pneumothorax
- ra rounded atelectasis
- rp rheumatoid pneumoconiosis
- tb tuberculosis

4C. MARK ALL BOXES THAT APPLY: (Use of this list is intended to reduce handwritten comments and is optional)

Abnormalities of the Diaphragm
- ☐ Eventration
- ☐ Hiatal hernia

Airway Disorders
- ☐ Bronchovascular markings, heavy or increased
- ☐ Hyperinflation

Bony Abnormalities
- ☐ Bony chest cage abnormality
- ☐ Fracture, healed (non-rib)
- ☐ Fracture, not healed (non-rib)
- ☐ Scoliosis
- ☐ Vertebral column abnormality

Lung Parenchymal Abnormalities
- ☐ Azygos lobe
- ☐ Density, lung
- ☐ Infiltrate
- ☐ Nodule, nodular lesion

Miscellaneous Abnormalities
- ☐ Foreign body
- ☐ Post-surgical changes/sternal wire
- ☐ Cyst

Vascular Disorders
- ☐ Aorta, anomaly of
- ☐ Vascular abnormality

4D. Should worker see personal physician because of findings? YES ☐ NO ☐

Date Physician or Worker notified? (mm-dd-yyyy) ☐☐ - ☐☐ - ☐☐☐☐

4E. OTHER COMMENTS

____
____
____
____
____
____
____

Figure 10: Standard form (page 2) used for grading a chest radiograph for pneumoconiosis within the ILO Classification System of Radiographs of Pneumoconioses.

Appendix 2 - Chest HRCT Grading System

The International Classification of high resolution computed tomography (HRCT) for Occupational and Environmental Respiratory Diseases (ICOERD) is the step-by-step method for grading HRCT [33]. The ICOERD was designed to complement the ILO Classification System while providing a method to classify the additional information that can be gained from chest HRCT imaging (Figure 11). The steps taken in assessing a chest HRCT using the ICOERD classification system are described below.

Normal vs positive

The first step in assessing a chest HRCT is to determine whether the film is completely negative. If the answer is no, the remainder of the form must be completed (Figure 12).

Rounded opacities: type and profusion ("ICOERD nodular grade")

Second, the chest HRCT is assessed for rounded opacities within the lung. Round opacities are described using the same three letters as the ILO system: p (<1.5 mm), q (1.5-3 mm) and r (3-10 mm). Profusion is assessed for each zone of the right and left lung and graded from 0 (no definitive opacities) to 3 (severe). The score for each zone is summated to equal a sum grade, with possible total sum grades ranging from 0 to 18. Within this report, this score is referred to as the "ICOERD nodular grade" (Figure 11, Nodular).

Irregular opacities: type and profusion ("ICOERD fibrosis grade")

Third, irregular or linear opacities (i.e. fibrosis) are assessed as present or absent, and the type determined. Types include subpleural curvilinear opacities (SC) or pleural linear opacities (PB). As above, grades from 0 to 3 are given for each lung zone, with a sum grade calculated. Within this report, this score is referred to as the "ICOERD fibrosis grade" (Figure 11, Fibrosis).

Inhomogeneous attenuation and ground glass opacity grade

Inhomogeneous attenuation, including mosaic perfusion or ground glass opacities (GGO), is assessed as present or absent. If GGO are present, grading is done for each side and zone, ranging from 1 (focal) to 3 (diffuse), with a sum grade calculated.

Honeycombing grade

Honeycombing is assessed as absent or present, and graded if present, with grades from 1 (mild) to 3 (severe), with a sum grade calculated.

Emphysema grade

Assessment of emphysema as absent or present, with the extent of emphysema graded from 1 (up to 15% of the area of one lung zone) to 3 (>30% of the area of lung zone affected). Grading is done for each side and zone, with a sum grade calculated. Within this report, this score is referred to as the "ICOERD emphysema grade" (Figure 11, Emphysema).

Large opacities

Large opacities (>10 mm) are assessed as absent or present, and assigned A, B or C depending on severity.

Pleural abnormalities
Assessment of pleural abnormalities, and description of characteristics including type and extent (graded 1 to 3), is undertaken if they are present.

Other abnormalities
Description of any other features of relevance, similar to the ILO system.

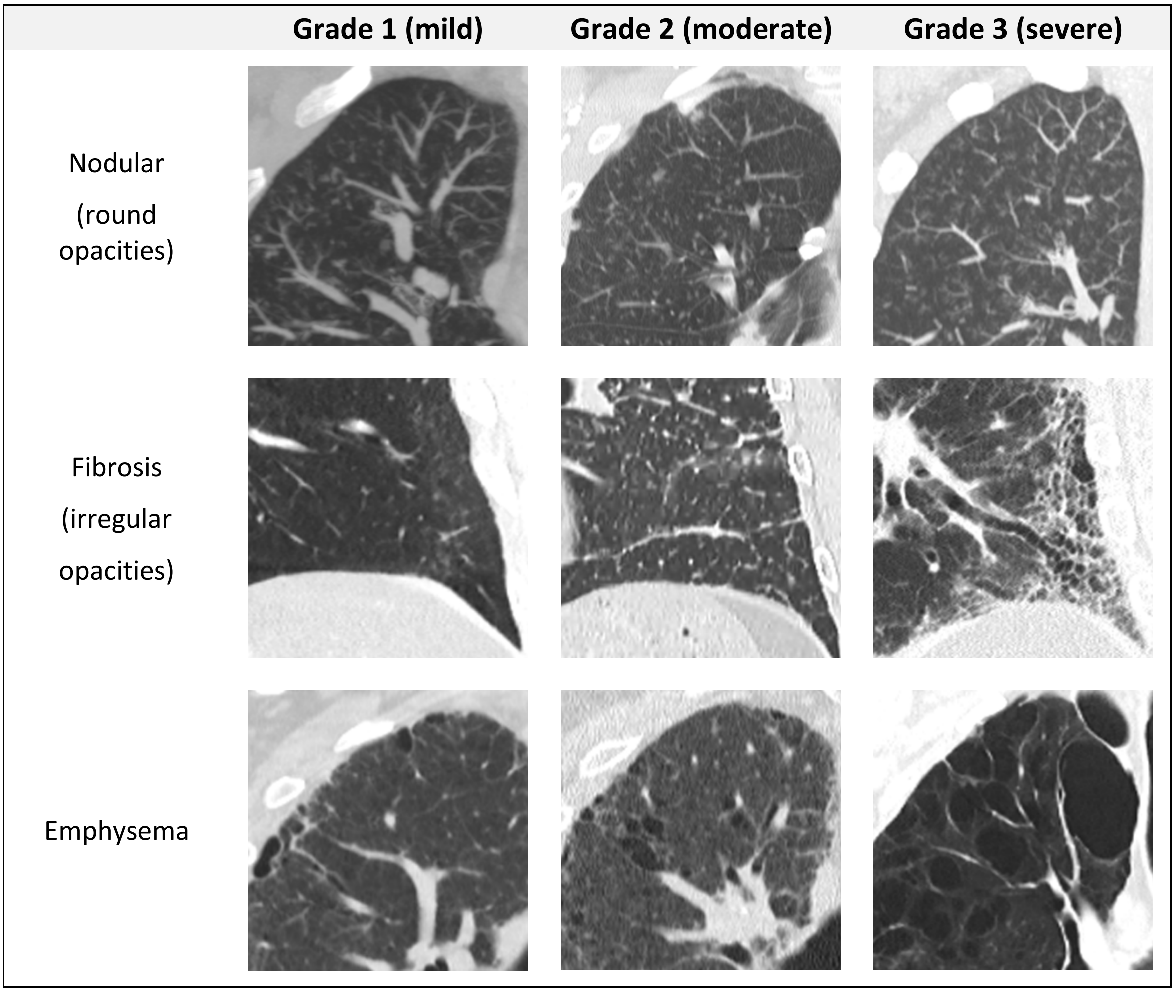
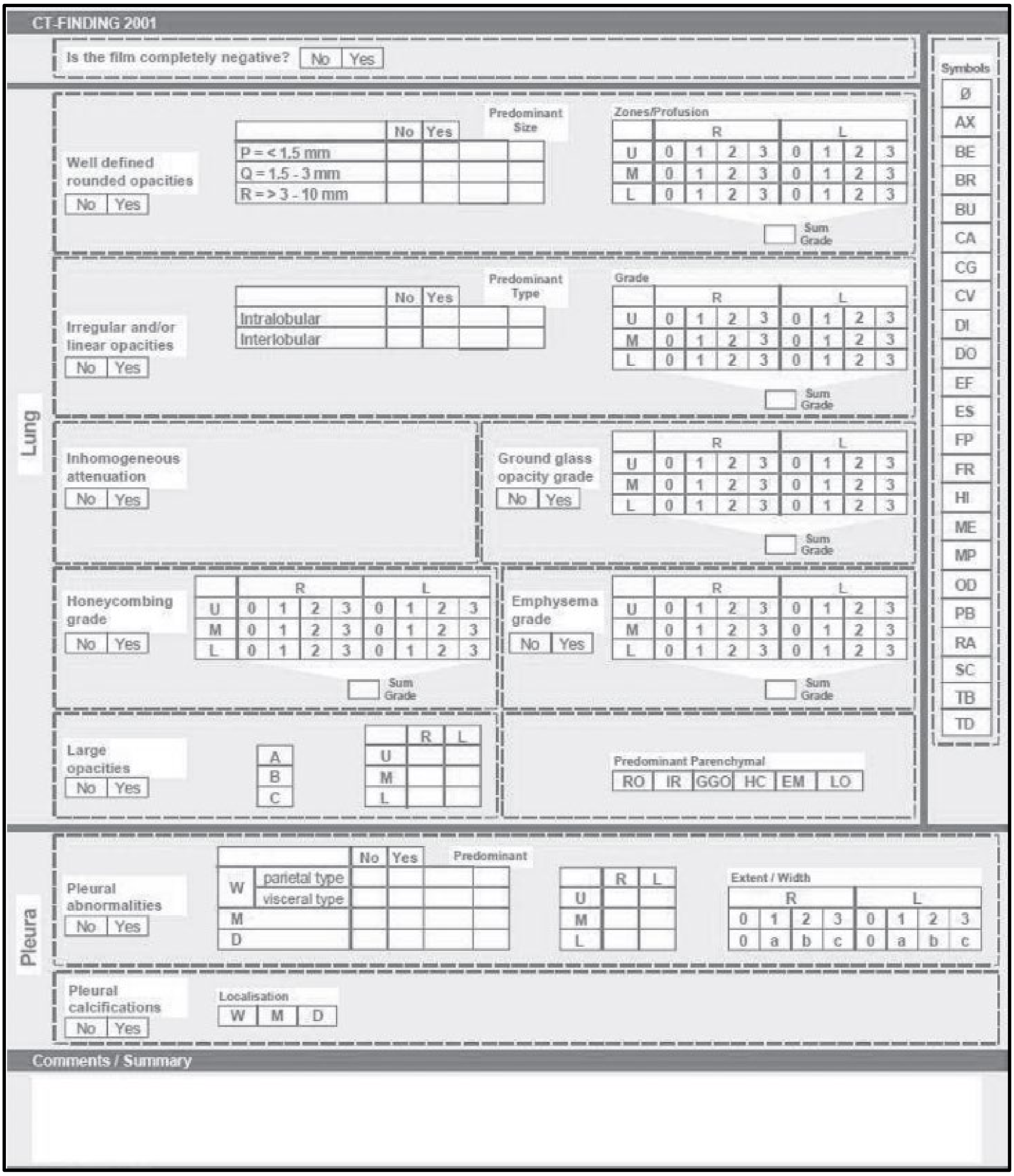


Figure 11: Chest HRCT radiological grades within the ICOERD classification system.



CT-FINDING 2001

Is the film completely negative? No | Yes

Lung

Well defined rounded opacities — No | Yes

	No	Yes	Predominant Size
P = < 1,5 mm			
Q = 1,5 - 3 mm			
R = > 3 - 10 mm			

Zones/Profusion

	R				L			
U	0	1	2	3	0	1	2	3
M	0	1	2	3	0	1	2	3
L	0	1	2	3	0	1	2	3

Sum Grade

Irregular and/or linear opacities — No | Yes

	No	Yes	Predominant Type
Intralobular			
Interlobular			

Grade

	R				L			
U	0	1	2	3	0	1	2	3
M	0	1	2	3	0	1	2	3
L	0	1	2	3	0	1	2	3

Sum Grade

Inhomogeneous attenuation — No | Yes

Ground glass opacity grade — No | Yes

	R				L			
U	0	1	2	3	0	1	2	3
M	0	1	2	3	0	1	2	3
L	0	1	2	3	0	1	2	3

Sum Grade

Honeycombing grade — No | Yes

	R				L			
U	0	1	2	3	0	1	2	3
M	0	1	2	3	0	1	2	3
L	0	1	2	3	0	1	2	3

Sum Grade

Emphysema grade — No | Yes

	R				L			
U	0	1	2	3	0	1	2	3
M	0	1	2	3	0	1	2	3
L	0	1	2	3	0	1	2	3

Sum Grade

Large opacities — No | Yes

A | B | C

	R	L
U		
M		
L		

Predominant Parenchymal: RO | IR | GGO | HC | EM | LO

Pleura

Pleural abnormalities — No | Yes

		No	Yes	Predominant
W	parietal type			
	visceral type			
M				
D				

	R	L
U		
M		
L		

Extent / Width

R				L			
0	1	2	3	0	1	2	3
0	a	b	c	0	a	b	c

Pleural calcifications — No | Yes

Localisation: W | M | D

Symbols: Ø, AX, BE, BR, BU, CA, CG, CV, DI, DO, EF, ES, FP, FR, HI, ME, MP, OD, PB, RA, SC, TB, TD

Comments / Summary

Figure 12: Standard form used for grading a chest HRCT for pneumoconiosis within the ICOERD system.

Appendix 3 – Box Plot Explanation

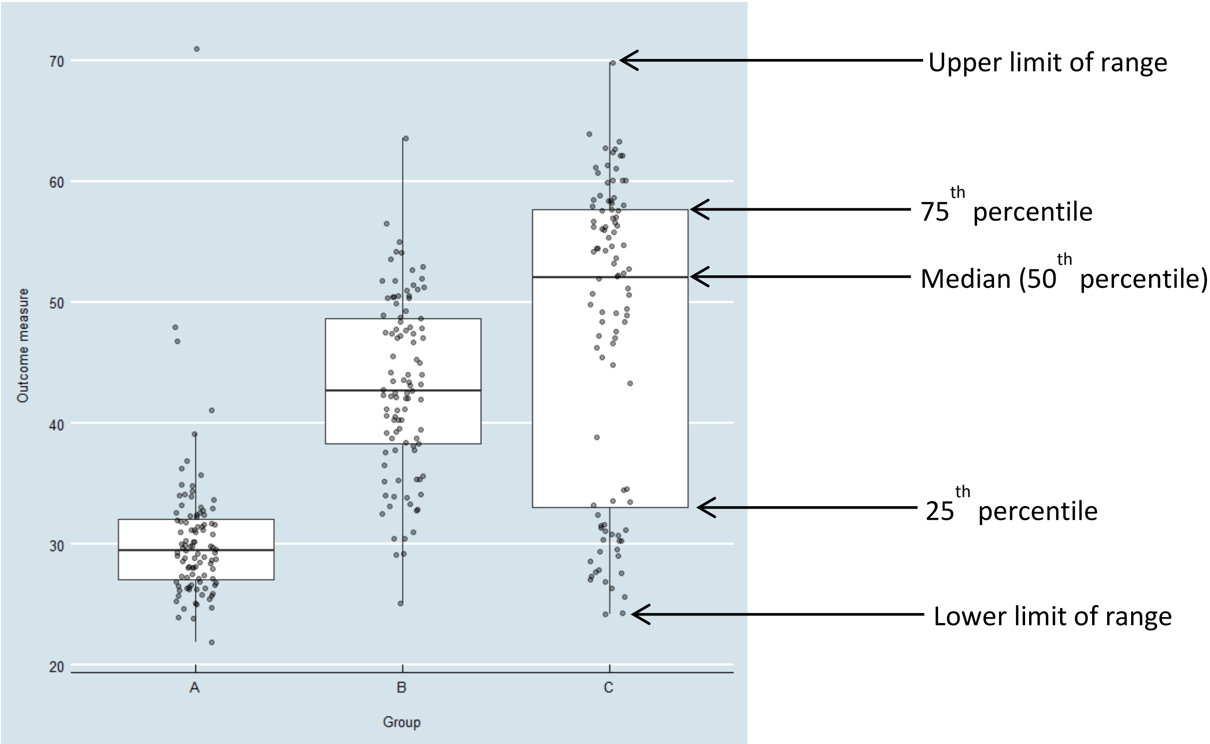


Figure 13: Example box plot with labels for interpretation.

Box plot figures are used to compare groups of scores by visualising distributions of each within a box and whisker structure. For a given group, the box contains all scores from the 25th percentile to the 75th percentile. The median is shown as the horizontal line within the box. The interquartile range (IQR) is the distance from the 25th to the 75th percentile. The whiskers, the vertical lines which extend from the box, reach to the highest and lowest scores which are within 1.5*IQR from the edge of the box. Individual data points are shown as dots on the plot. Horizontal displacement of these individual data points is used to prevent overlapping.

Appendix 4 - Spirometry Assessment

The TSANZ algorithm for interpretation of spirometry in coal workers describes the process for identifying normal, or obstructive and restrictive lung disease as per the flow chart below [40].

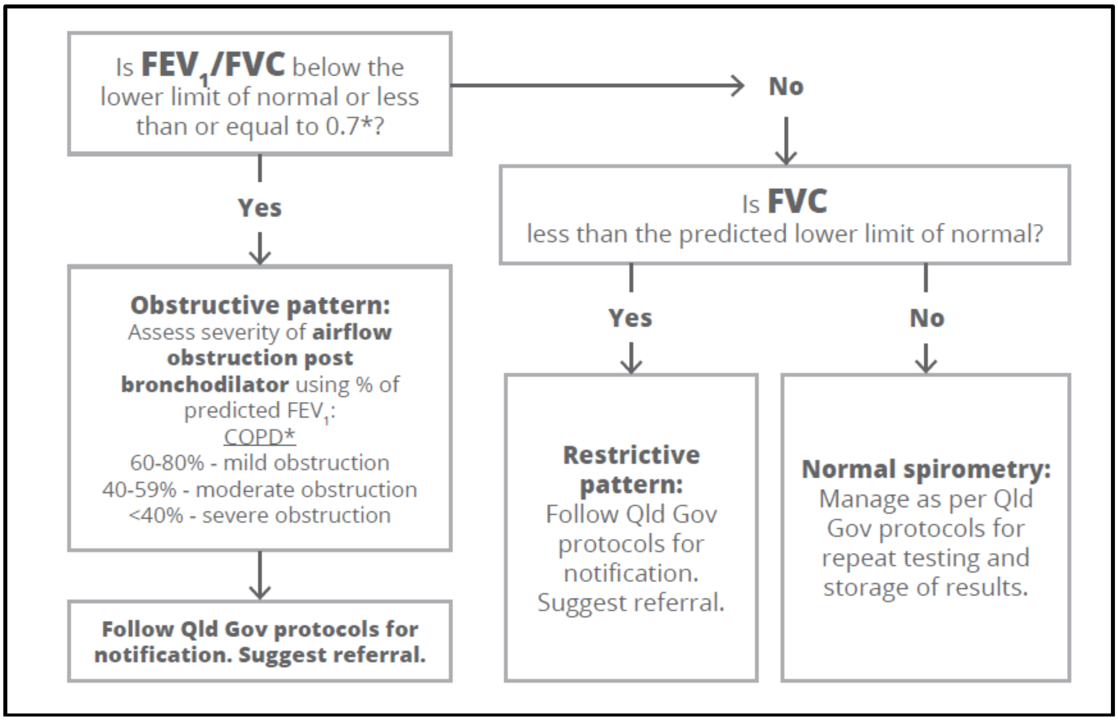


Figure 14: TSANZ spirometry interpretation process for abnormal lung function detection.

Appendix 5 - Questionnaires

The questionnaires were administered in interviews with subjects to collect in-depth information for this research study. The questionnaires were completed electronically. The questionnaire was designed to be customised for each respondent - basic information was gathered first, which then tailored subsequent questions within the questionnaire. For example, a respondent who indicated that they had worked in open-cut coal mining only would skip sections relating to underground coal mining. Given the electronic nature of the questionnaires, this tailoring functionality, and the large number of potential questions, it was deemed not feasible to reproduce the full questionnaires here.

OCCUPATIONAL HISTORY QUESTIONNAIRE

1. Personal information (2 questions)
Full name and DOB.

2. Basic coal mining history (11 questions)
First and last years worked in the coal mining industry.
Select mine type: open-cut, underground, or both.
List mine sites worked at.
Select areas worked in e.g. CHPP, longwall production, returns.

3. Detailed mining history (2 questions)
Indicate which roles were conducted, at which mines sites, and in which years.

4. Roster type (6 questions)
Describe roster type worked across career, including roster style and hours per month across each mine site.

5. Contract work (3 questions)
Indicate whether ever worked as a contractor, and if so where.

6. General PPE (4 questions)
For each mine site worked at, select what type of PPE was used.

7. Detailed PPE and exposure history (11 questions)
Indicate whether ever fit-tested for PPE.
Rate opinion of dust control effectiveness at each mine site.
Indicate whether ever wore personal dust monitoring devices, and if so provide further details as to how often and at which mine sites.
Indicate whether exposed to diesel fumes and if so provide further detail.

8. Union membership (3 questions)
Indicate whether currently a union member and, if so, whether the union is aware of CMDLD assessment.

9. Dust risk education (3 questions)

Indicate understanding of dust-associated health risks, and rating of education provided at each mine site.

10. General information on open-cut mines worked at (3 questions)
For each open-cut mine site worked at, indicate the method used such as dragline or shovel and excavator.

11. Detailed open-cut SEGs (68 questions)
Detailed questions on which open-cut SEGs were worked in across their career, with further questions on the dust mitigation strategies employed, PPE, and visibility for each SEG at each mine site. SEGs were defined as per the DNRME 2017 [56].

12. General information on underground mines worked at (3 questions)
For each underground mine site worked at, indicate the characteristics of the mine, including whether methane was drained and the seam type. Indicate the percentage of the shift spent underground, and the percentage of time spent within 30 m of the coal face.

13. Detailed underground SEGs (34 questions)
Detailed questions on which underground SEGs were worked across their career, with further detail on the machinery operated, dust mitigation strategies and PPE used for each SEG at each mine site.

14. General information on hard rock mining (2 questions)
Indicate whether ever worked in mines other than coal. And if so, select which mine types, for example, gold, gems or zinc.

15. Detailed hard rock mining (20 questions)
Detail further information on hard rock mining, inclusive of whether above or underground, the machinery operated, dust mitigation strategies, PPE, and visibility for each hard rock mine worked at.

RESPIRATORY HEALTH HISTORY QUESTIONNAIRE

1. Modified Medical Research Council Dyspnoea Scale (1 question)
Five point scale quantifying whether breathlessness occurs when it shouldn't.

2. Clinical COPD Questionnaire (10 questions)
Health-related quality of life assessment incorporating questions on symptoms, functional state and mental health.

3. The Medical Research Council Questionnaire, version 1976 (41 questions)
Assessment tool comprising questions on respiratory symptoms as well as smoking history.

4. Non-occupational exposures (5 questions)

Indicate history of environmental exposure to dust or antigens known to cause lung diseases, for example, asbestos, pottery, concreting, and bird keeping. If had previous exposure to any of these, additional questions asked to quantify exposure.

5. Other clinical history of relevance (6 questions)

Indicate a history of prior radiation therapy, lung cancer diagnosis, other chest health problems, and any medications for these, for example, inhalers.

Appendix 6 – Additional Multi-disciplinary Figures and Table

Figures and table from chapter 6.3.1 describing disease severity as assessed on radiology and spirometry

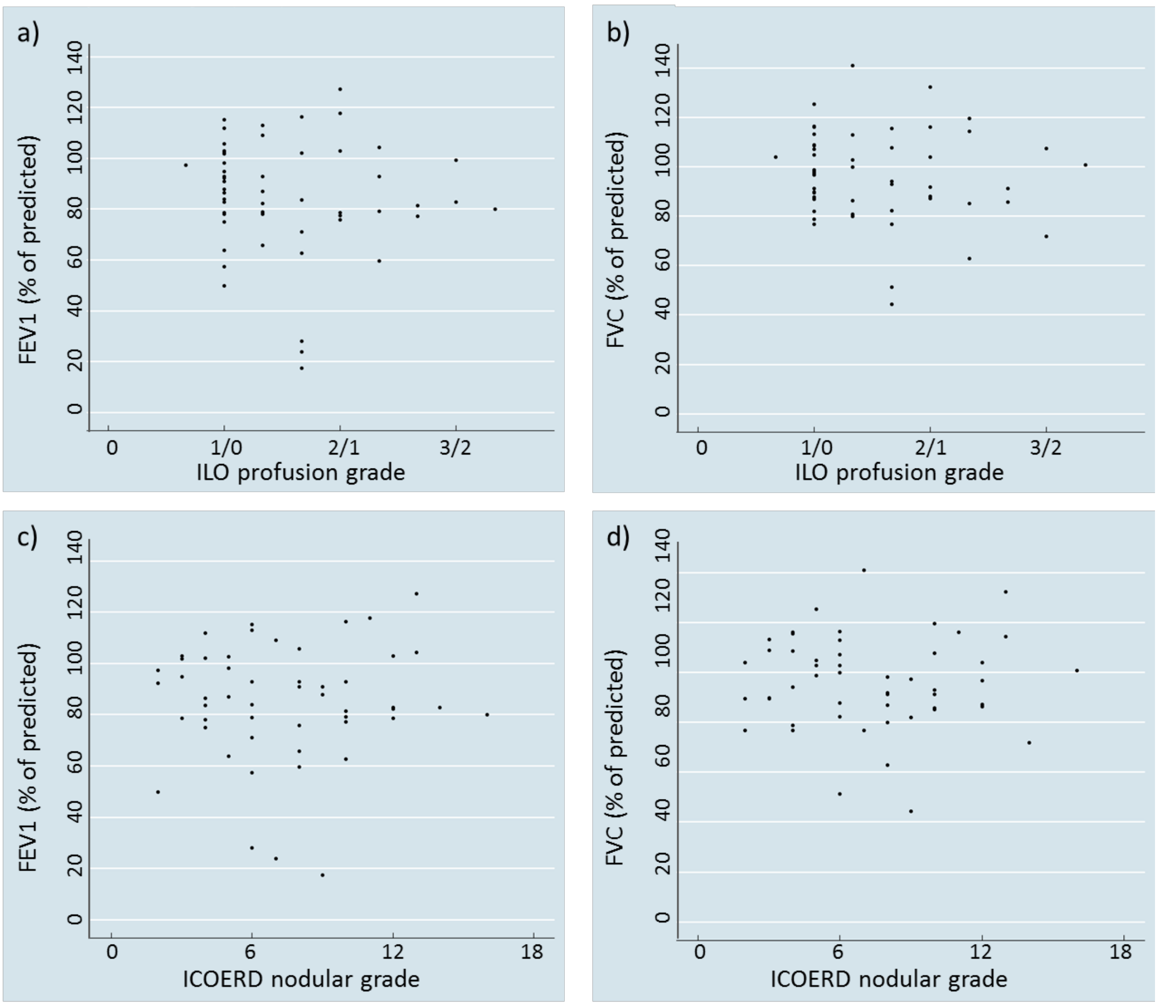


Figure 15: Disease severity assessed by radiological grades and spirometry values. Correlation between FEV1% and FVC% and severity of nodular CMDLD as assessed by ILO profusion grade on chest radiograph (15a and 15b); and ICOERD nodular grade on HRCT (15c and 15d).

Table 15: Comparisons of disease severity assessed by radiological grades and spirometry.

Comparison variables		Relevant figure	p-value	Estimate	95% CI lower	95% CI upper
ILO profusion grade	FEV1 (% of predicted)	15a	0.61	-0.83	-4.08	2.41
ILO profusion grade	FVC (% of predicted)	15b	0.55	-0.80	-3.47	1.86
ICOERD nodular grade	FEV1 (% of predicted)	15c	0.73	0.32	-1.56	2.21
ICOERD nodular grade	FVC (% of predicted)	15d	0.91	-0.09	-1.63	1.46

REFERENCES

1. Petsonk EL, Rose C, Cohen R. Coal mine dust lung disease. New lessons from an old exposure. *American Journal of Respiratory and Clinical Care Medicine* 2013; **187**(11):1178-85.

2. Wade WA, Petsonk EL, Young B, et al. Severe occupational pneumoconiosis among West Virginian coal miners: one hundred thirty-eight cases of progressive massive fibrosis compensated between 2000 and 2009. *Chest* 2011; **139**(6):1458-62.

3. Roth GA, Abate D, Abate KH, et al. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet* 2018; **392**(10159):1736-88.

4. dos S Antao VC, Petsonk EL, Sokolow LZ, et al. Rapidly progressive coal workers' pneumoconiosis in the United States: geographic clustering and other factors. *Occupational and Environmental Medicine* 2005; **62**(10):670-74.

5. Laney AS, Attfield MD. Coal workers' pneumoconiosis and progressive massive fibrosis are increasingly more prevalent among workers in small underground coal mines in the United States. *Occupational and Environmental Medicine* 2010; **67**(6):428-31.

6. Blackley DJ, Halldin CN, Laney AS. Continued increase in prevalence of coal workers' pneumoconiosis in the United States, 1970-2017. *American Journal of Public Health* 2018; **108**(9):1220-22.

7. Blackley DJ, Halldin CN, Laney AS. Resurgence of a debilitating and entirely preventable respiratory disease among working coal miners. *American Journal of Respiratory and Clinical Care Medicine* 2014; **190**(6):708-09.

8. Han S, Chen H, Harvey M-A, et al. Focusing on coal workers' lung diseases: a comparative analysis of China, Australia, and the United States. *International Journal of Environmental Research and Public Health* 2018; **15**(11):2565.

9. Mo J, Wang L, Au W, et al. Prevalence of coal workers' pneumoconiosis in China: A systematic analysis of 2001–2011 studies. *International Journal of Hygiene and Environmental Health* 2014; **217**(1):46-51.

10. International Labour Organisation. The prevention of occupational diseases. 1st edition. International Labour Organisation, Geneva, Switzerland, 2013. Available from: https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/publication/wcms_208226.pdf

11. Rathus EM, Abrahams EW. Chest x-ray and emphysema check survey of colliery employees in Queensland. The Queensland Coal Board Coal Miners' Health Scheme, Queensland, Australia, 1984. Available from: https://publications.qld.gov.au/dataset/35d98936-da23-4be8-bc8a-

c1d8ca5d8d54/resource/52a698e3-eb3f-4940-b1a8-ab82776196b2/download/rathusreport1984.pdf

12. Sim M, Glass D, Hoy R, et al. Review of respiratory component of the Coal Mine Workers' Health Scheme for the Queensland Department of Natural Resources and Mines. Department of Natural Resources and Mines, Queensland, Australia, 2016. Available from: https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0009/383940/monash-qcwp-final-report-2016.pdf

13. Coal Workers' Pneumoconiosis Select Committee. Black lung white lies; inquiry into the re-identification of coal workers' pneumoconiosis in Queensland. Coal Workers' Pneumoconiosis Select Committee, Queensland, Australia, 2017. Available from: https://www.parliament.qld.gov.au/documents/tableOffice/TabledPapers/2017/5517T815.pdf

14. Australian Bureau of Statistics. History of coal mining. Year Book Australia, 1910. Australian Government, Canberra, Australia, 1910. Available from: http://www.abs.gov.au/ausstats/abs@.nsf/featurearticlesbytitle/6893596390A01028CA2569E3001F5555

15. Australian Bureau of Statistics. Queensland year book. Australian Government, Canberra, Australia, 2001. Available from: http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/71E6D1E2596EADF7CA256A0200023392/$File/13013_2001.pdf

16. Australian Bureau of Statistics. Australian industry 2016-17. Australian Government, Canberra, Australia, 2018. Available from: https://www.abs.gov.au/ausstats/abs@.nsf/mf/8155.0

17. Department of Health and Human Services. Coal Mine Dust Exposures and Associated Health Outcomes. Department of Health and Human Services , Ohio, USA, 2011. Available from: https://www.cdc.gov/niosh/docs/2011-172/pdfs/2011-172.pdf

18. Safe Work Australia. Workplace Exposure Standards for Airborne Contaminants. Safe Work Australia, Canberra, Australia, 2018. Available from: https://www.safeworkaustralia.gov.au/system/files/documents/1804/workplace-exposure-standards-airborne-contaminants-2018_0.pdf

19. Department of Natural Resources, Mines and Energy. Coal mining safety and health regulation 2017. Queensland Government, Queensland, Australia, 2018. Available from: https://www.legislation.qld.gov.au/view/html/inforce/current/sl-2017-0165

20. Collis EL, Gilchrist JC. Effects of dust upon coal trimmers. *Journal of Industrial Hygiene* 1928; **10**:101-10.

21. Honma K, Abraham JL, Chiyotani K, et al. Proposed criteria for mixed-dust pneumoconiosis: Definition, descriptions, and guidelines for pathologic diagnosis and clinical correlation. *Human Pathology* 2004; **35**(12):1515-23.

22. Williams JL, Moller GA. Solitary Mass in the Lungs of Coal Miners. *American Journal of Roentgenology* 1973; **117**(4):765-70.

23. McConnochie K, Green FHY, Vallyathan V, et al. Interstitial fibrosis in coal workers—Experience in Wales and West Virginia. *Annals of Occupational Hygiene* 1988; **32**(1):S553–S60.

24. Brichet A, Tonnel A, Brambilla E, et al. Chronic interstitial pneumonia with honeycombing in coal workers. *Sarcoidosis, Vasculitis and Diffuse Lung Diseases* 2002; **19**(3):211-19.

25. Cockcroft A, Berry G, Cotes J, et al. Shape of small opacities and lung function in coalworkers. *Thorax* 1982; **37**(10):765-69.

26. Brusasco V, Pellegrino R. Spirometry in Chronic Obstructive Pulmonary Disease. From rule of thumb to science. *American Journal of Respiratory and Clinical Care Medicine* 2016; **193**(7):704-06.

27. Pauwels RA, Buist AS, Calverley PM, et al. Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease. NHLBI/WHO Global Initiative for Chronic Obstructive Lung Disease (GOLD) workshop summary. *American Journal of Respiratory and Clinical Care Medicine* 2001; **163**(5):1256-76.

28. Torén K, Vikgren J, Olin A-C, et al. Occupational exposure to vapor, gas, dust, or fumes and chronic airflow limitation, COPD, and emphysema: the Swedish CArdioPulmonary BioImage study (SCAPIS pilot). *International Journal of Chronic Obstructive Pulmonary Disease* 2017; **12**:3407-13.

29. World Health Organisation. Chronic Respiratory Conditions; COPD: Definition. World Health Organisation, 2018. Available from: https://www.who.int/respiratory/copd/definition/en/

30. Hurley JF, Alexander WP, Hazledine DJ, et al. Exposure to respirable coalmine dust and incidence of progressive massive fibrosis. *British Journal of Industrial Medicine* 1987; **44**(10):661-72.

31. Xing J, Huang X, Yang L, et al. Comparison of high-resolution computerized tomography with film-screen radiography for the evaluation of opacity and the recognition of coal workers' pneumoconiosis. *Journal of Occupational Health* 2014; **56**(4):301-08.

32. Remy-Jardin M, Remy J, Farre I, et al. Computed tomographic evaluation of silicosis and coal workers' pneumoconiosis. *Radiologic Clinics of North America* 1992; **30**(6):1155-76.

33. Kusaka Y, Hering KG, Parker JE. International Classification of HRCT for Occupational and Environmental Respiratory Diseases. Tokyo, Springer Tokyo, 2005.

34. International Labour Organisation. Guidelines for the use of the ILO international classification of radiographs of pneumoconioses. Revised edition. International Labour Organisation, Geneva, Switzerland, 2011. Available from: https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/publication/wcms_168260.pdf

35. Han L, Han R, Ji X, et al. Prevalence characteristics of coal workers' pneumoconiosis (CWP) in a state-owned mine in Eastern China. *International Journal of Environmental Research and Public Health* 2015; **12**(7):7856-67.

36. Antao VC, Petsonk EL, Attfield MD. Advanced cases of coal workers' pneumoconiosis - Two counties, Virginia, 2006. *Morbidity and Mortality Weekly Report* 2006; **55**(33):909-13.

37. Suarthana E, Laney AS, Storey E, et al. Coal workers' pneumoconiosis in the United States: regional differences 40 years after implementation of the 1969 Federal Coal Mine Health and Safety Act. *Occupational and Environmental Medicine* 2011; **68**(12):908-13.

38. Buchanan D, Miller B, Soutar C. Quantitative relations between exposure to respirable quartz and risk of silicosis. *Occupational and Environmental Medicine* 2003; **60**(3):159-64.

39. Laney AS, Petsonk EL, Attfield MD. Pneumoconiosis among underground bituminous coal miners in the United States: is silicosis becoming more frequent? *Occupational and Environmental Medicine* 2010; **67**(10):652-56.

40. Thoracic Society of Australia and New Zealand. Standards for the Delivery of Spirometry for Coal Mine Workers. Thoracic Society of Australia and New Zealand, Queensland, Australia, 2017. Available from: https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0003/1274421/tsanz-spirometry-standards.pdf

41. Williams N. The MRC breathlessness scale. *Occupational Medicine* 2017; **67**(6):496-97.

42. Cotes JE, Chinn DJ. MRC questionnaire (MRCQ) on respiratory symptoms. *Occupational Medicine* 2007; **57**(5):388-88.

43. van der Molen T, Willemse BWM, Schokker S, et al. Development, validity and responsiveness of the Clinical COPD Questionnaire. *Health and Quality of Life Outcomes* 2003; **1**(1):13-23.

44. Uzel Şener M, Şimşek C, Özkara Ş, et al. Comparison of the international classification of High-Resolution Computed Tomography for occupational and environmental respiratory diseases with the International Labour Organization International classification of radiographs of pneumoconiosis. *Industrial Health* 2018; epub ahead of print. DOI: 10.2486/indhealth.2018-0068.

45. Brhel P, Petrovová M, Lorenzová D. Ventilatory function in patients with silicosis or coal workers' pneumoconiosis. *Vnitrni lekarstvi* 2015; **61**(12):1023-27.

46. Lai H, Liu Y, Zhou M, et al. Combined effect of silica dust exposure and cigarette smoking on total and cause-specific mortality in iron miners: a cohort study. *Environmental Health* 2018; **17**(1):46-56.

47. Altinöz H, Çelikkalkan C, Horasan GD, et al. Socio-demographic and clinical characteristics of Turkish workers with pneumoconiosis. *Central European Journal of Public Health* 2016; **24**(3):231-33.

48. Pellegrino R, Viegi G, Brusasco V, et al. Interpretative strategies for lung function tests. *European Respiratory Journal* 2005; **26**(5):948-68.

49. Miller MR, Quanjer PH, Swanney MP, et al. Interpreting lung function data using 80% predicted and fixed thresholds misclassifies more than 20% of patients. *Chest* 2011; **139**(1):52-59.

50. Armstrong B, McNulty J, Levitt L, et al. Mortality in gold and coal miners in Western Australia with special reference to lung cancer. *Occupational and Environmental Medicine* 1979; **36**(3):199-205.

51. Leigh J, Wiles A, Glick M. Total population study of factors affecting chronic bronchitis prevalence in the coal mining industry of New South Wales, Australia. *Occupational and Environmental Medicine* 1986; **43**(4):263-71.

52. Torres Rey CH, Ibañez Pinilla M, Briceño Ayala L, et al. Underground coal mining: relationship between coal dust levels and pneumoconiosis, in two regions of Colombia, 2014. *BioMed Research International* 2015; **2015**:1-8.

53. Morfeld P, Ambrosy J, Bengtsson U, et al. The risk of developing coal workers' pneumoconiosis in German coal mining under modern mining conditions. *Annals of Occupational Hygiene* 2002; **46**(sup1):S251-S53.

54. Perret JL, Plush B, Lachapelle P, et al. Coal mine dust lung disease in the modern era. *Respirology* 2017; **22**(4):662-70.

55. Ross MH, Murray J. Occupational respiratory disease in mining. *Occupational Medicine* 2004; **54**(5):304-10.

56. Department of Natural Resources, Mines and Energy. Similar Exposure Groups (SEGs). Queensland Government, Queensland, Australia 2017. Available from: https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0008/977498/similar-exposure-groups.pdf

57. Mulhausen JR, Damiano J. A strategy for assessing and managing occupational exposures. 2nd edition. American Industrial Hygiene Association, Exposure Assessment Strategies Committee, Virginia, Fairfax Virginia, 1998.

58. Qualtrics. Qualtrics. Provo, Utah, USA: Qualtrics, 2018. Available from: https://www.qualtrics.com

59. R Core Team. A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing, 2018. Available from: https://www.R-project.org/