Exposure to Nano Diesel Particulate Matter (nDPM) and health impacts in Underground Hard Rock Miners in Western Australia

Report to the Department of Mines, Industry Regulation and Safety

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Executive summary

Introduction

Diesel Engine Exhaust (DEE) is emitted from a variety of on-road (e.g. motor vehicles, construction equipment) and off-road sources (e.g. farm equipment, mining equipment, railway engines etc.). DEE is a complex mix of many constituents in their gaseous or particulate phase. The gaseous pollutants are dominated by oxides of nitrogen (NO_x), carbon monoxide (CO) and sulphur oxides, however also include oxygen, carbon dioxide, nitrogen and water vapour. The particulate phase is termed Diesel Particulate Matter (DPM), which is composed of elemental/black carbon with ad/ab-sorbed organic carbon compounds and trace levels of metals. Exposure to diesel engine exhaust, in the occupational and non-occupational environment has been linked with a range of non-malignant respiratory symptoms and diseases. In addition, DEE emissions were declared carcinogenic to humans by the World Health Organisations' International Agency for Research on Cancer (IARC) in 2012. The standard measure for occupational exposure to DEE requires the Elemental Carbon (EC) component of DPM to be monitored for a cross section of exposed workers. However there is some debate as to whether this measure gives the best indication of possible health effects, which may be more closely linked to the organic or gaseous components, or DEP size or surface area rather than mass (of EC).

Underground mining in Western Australia relies heavily on diesel engine powered equipment. Exposure to diesel exhaust emissions has declined in recent years (due to improved work practices, mine ventilation and engine/after treatment technology), but is still substantial particularly in underground workers and especially those operating diesel powered plant and equipment. Diesel engine technology has progressively improved over time and emissions from these new technology diesel engines have significantly reduced DEP (both number and mass/EC), NO_x and CO, however "off-highway" emissions standards (especially in Australia) lag behind more stringent "on-highway" emissions standards. In addition, mine plants have a long service life, so older equipment is often used, possibly with retrofitted emissions control which is not required to undergo compliance testing. In addition to the above, most research on DEE health effects is focussed on exposure to surface workers, which may not be equivalent to mine exposures.

Aims

The overall aim of this study was to ascertain the health effects of exposure to diesel particulate emissions on underground and above ground miners of Western Australia. Specifically we examined;

a. the prevalence of respiratory symptoms (cough and phlegm, breathlessness, airflow obstruction, history of asthma and allergic rhinitis).

b. changes in lung function across the working shift in relation to diesel exposure and smoking.

c. changes in level of urinary 1-hydroxypyrene (1-OHP) and 1-Aminopyrene (1-AP) across the working shift in relation to diesel exposure and smoking.

d. DNA methylation in blood in relation to diesel exposure estimates and smoking.

e. levels of blood pressure in relation to diesel exposure estimates and smoking.

f. determine which measures of DEE were more closely correlated with the above – e.g. NO_2, EC, Particle Number.

Methods

Twenty above ground and 80 below ground miners, working at Anglo Gold's Sunrise Dam mine in Western Australia were recruited into this study. Field work occurred over two weeks in October 2017. Five participants were recruited at each shift change and after giving informed consent, completed a questionnaire, and underwent a series of physical measurements (e.g. blood pressure, weight and height, lung function tests) and provided a urine sample. They were then fitted with personal exposure monitoring equipment [refer M495 part B report for personal monitoring methods] and commenced their work shift. At the end of their shift, participants returned to the study area and had the personal monitoring equipment removed. They did further lung function tests (with and without bronchodilator (salbutamol), provided a second urine sample, had blood collected and completed a questionnaire about the tasks they had done throughout their shift.

1-hydroxypyrene (1-OHP) was assayed in urine samples by ChemCentre and 1-Aminopyrene (1-AP) was assayed in urine samples at Curtin University. Blood samples were sent to PathWest for DNA methylation and results sent to the Curtin/UWA Centre for Genetic Origins of Health and Disease for statistical analysis and quality control.

Student t test was used to compare statistical differences between underground and above ground miners for normally distributed variables (e.g. age, systolic blood pressure, lung functions tests, etc.). Mann–Whitney U test was conducted for non-normally distributed variables (e.g. shift on swing, 1-AP, 1-OHP, elemental carbon (EC), volatile organic compounds (VOCs), particle number, etc.). Chi-squared test was used for categorical data, including sex (female/ male), nativity (Australian-born/others), smoking status (never, former and current), physical activity (yes/no), BMI (<25, 25-29.9 and $>=30$), and respiratory symptoms. Wilcoxon signed-rank test compared the difference between pre- and post-shift levels of urinary biomarkers in each group. Multiple linear regressions assessed the association between cross-shift changes in lung function and environmental diesel exposures, including elemental carbon, VOCs, NO_2, particle number and particle size, after adjusted confounding factors (smoking status, total years in mining industry, shift on swing and basic respiratory symptoms). Linear mixed effects models for repeated measures assessed the association between environmental diesel exposures and levels of urinary biomarkers among all participants. We included age, sex, smoking status, shift on swing and years in mining in the models to adjust for potential confounding. Additionally, separate generalized linear regression models were also used to test the association between systolic blood pressure and different exposures, adjusting for age, sex, BMI, smoking status, years in mining and shift on swing as potential confounding factors.

A linear model with CpG site as the outcome variable was run on eight phenotypes; Above/Underground workers; years in the mining industry; shift on swing; N0x, particle count, EC, particle size and total VOCs, adjusted for age, sex and smoking status while accounting for batch effects and cellular heterogeneity. Differentially methylated regions were identified with the array and sequencing spatial analysis method DMRcate and a conservative Stouffer cut-off<0.05. Gene enrichment analysis was done using Miss Methyl on only the variants with a p-value <0.001. All DNA methylation analyses were run using the R statistical software program.

Results

Underground miners had considerably greater exposure to elemental carbon, volatile organic compounds, nitrogen dioxide, lung deposited surface area, particle number and particle size, than above ground miners. There was no difference in exposure levels between day and night shift. In terms of health status, underground miners showed declines in lung function across the work-shift, which were greater than those observed in above ground miners, and which were related to DPM exposure. Similarly pre and post shift urinary biomarkers (1-AP and 1-OHP) of DPM exposure were higher in underground miners than above ground miners, and both biomarkers increased across the shift in underground miners. Systolic blood pressure, taken at the start of the shift, increased significantly with increased exposure to Nitrogen dioxide and particle size. Forty one differentially methylated CpG sites in seven phenotypes were identified. Twenty nine of these sites where in known gene regions and 12 were intergenic. Twelve of the 29 genes were associated with known chronic diseases including cancer (3 genes), cardiovascular disease (3 genes) and epilepsy (2 genes).

Conclusion

Whilst different compounds of DPM (EC, VOCs, NO_2, LDSA and particle number) were correlated, EC, particle number and NO_2 tended to serve as better predictors of health measures. The monitoring report (M495 – Part B) showed that the implementation of emissions control measures in the mine have resulted in a decrease in modal particle size compared to previous studies. These findings (plus other diesel exposure research cited) reinforce the need to monitor EC and or surface area exposure among miners, in addition to particle number and NO_x. Maintaining EC surveillance is also important to allow comparison with existing datasets.