

Respiratory Diseases Due to Occupational Exposure to Nickel and Chromium among Factory Workers in Kenya

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Abstract

Inhalation of airborne nickel (Ni) and chromium (Cr) in workplaces causes a variety of respiratory ailments which adversely affects the productivity of employees. A study was therefore conducted on production workers (N=233) from six different types industrial plants, to investigate the influence of Ni and Cr exposure on their respiratory systems. Breathing zone air and urinary samples were collected, and analyzed for total Ni and Cr using atomic absorption spectroscopy. The medical history of the workers was obtained using questionnaires. Their lung functions were further examined using a spirometer. Mean (\pm standard deviation) breathing zone air of $23.4 \pm 11.6 \mu\text{g}/\text{m}^3$ Cr and $10.3 \pm 4.3 \mu\text{g}/\text{m}^3$ Ni was highest among the tanners and welders, respectively. The mean level of 35.2 ± 12.1 Cr and 28.4 ± 7.8 Ni in $\mu\text{g}/\text{g}$ creatinine were also highest in the urine of corresponding workers. A significant ($P < 0.01$) correlation of $r = 0.86$ Cr and $r = 0.89$ Ni was observed between airborne and urinary levels in all production workers. Approximately 26.6% of the workers had respiratory diseases that were associated with wheezing, shortness of breath, sneezing attacks among other related symptoms. Most of these workers were welders, tanners and, to lesser extent, paint manufacturers. The breathing zone air of the afflicted workers had significantly ($P < 0.05$) high mean levels of $6.4 \pm 4.4 \mu\text{g}/\text{m}^3$ Ni and $9.6 \pm 5.3 \mu\text{g}/\text{m}^3$ Cr than those who were not affected ($3.9 \pm 3.2 \mu\text{g}/\text{m}^3$ Ni and $4.4 \pm 3.8 \mu\text{g}/\text{m}^3$ Cr). A high proportion of the workers had reduced ventilatory function measurements. We recommend comprehensive assessment of Cr and Ni in related industries with significant exposures. Designing and developing of training programs and educative manuals on safety and health procedures, and regular medical surveillance is also recommended.

Keywords: Lung function; Nickel; Chromium; Respiratory related symptoms; Tanners; Welders; Medical surveillance; Training programs

Introduction

Hexavalent chromium [(Cr (VI)) and nickel (Ni) are among the heavy metals with established history of detrimental health effects [1-6]. Epidemiological studies have consistently shown that chronic exposure to Ni and Cr (VI) compounds through inhalation is associated with higher incidences of lung cancers and respiratory ailments [1,2]. Health concerns are therefore raised over these metals due to possible exposure because of their widespread use and availability in manufacturing processes. Elevated temperatures that are often involved in most industrial activities, including welding result in emission of particulate matter in the form of metal dust, fumes and oxides, which are easily inhaled [1,5]. These particulate materials are then absorbed and thereafter penetrate deeper into membranes of human lungs, leading to respiratory manifestations such as those of severe bronchial complications, lung emphysema, chronic obstructive pulmonary disease, renal dysfunction and death [1,5,7]. The latter may occur due to pulmonary oedema [1]. Diseases that are associated with respiratory systems are usually observable by one or more related symptoms including wheezing sinusitis and shortness of breath [1,4,7]. Early intervention measures at this level may therefore save many workers from the adverse health effects that are caused by exposure to Ni and Cr [3,5,6].

Previous studies by Were et al. [8] reported that air quality in industrial environments in Kenya is increasingly deteriorating in terms of presence of pollutants from the use of unsafe technologies and poor work practices. Additionally, the population of low-income earners is relatively high in this area and monitoring of their workplaces, and enforcement of relevant laws are a serious challenge [8,9]. The limited resources for performing Cr and Ni analysis in air and biological media further aggravate the situation [7]. This consequently implies that the nature, magnitude and severity of Cr and Ni exposures among workers have not been adequately investigated, and addressed in Kenya. The

incidences of chronic exposure to Ni and Cr and related adverse health effects is likely to increase in manufacturing establishments especially during this anticipated phase of rapid industrialization in Kenya [9]. The study was consequently conducted among production workers across diverse plants in order to investigate the extent of exposure to Ni and Cr and the health impact on their respiratory systems.

Materials and Methods

Study area and participants

All ethical issues in regard to this study were sought from relevant authorities at the National Commission for Science, Technology and Innovation, the Ministry of Medical Services, Office of the Director Medical Services, Nairobi and the Directorate of Occupational Health Services, Nairobi in Kenya. The field activities and related survey began in April 2011 and ended in April 2012. The research design was a cross-sectional study within a range of six varied industrial plants in Industrial Area, Nairobi. It involved the collection and analysis of spot urine and breathing zone air samples from production workers in order to evaluate Ni and Cr exposures. Medical personnel further carried out lung function examinations using a spirometer. The respiratory related symptoms were self reported by the participants through interviews

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and a standard questionnaire. Manufacturing processes, working conditions and the safety behavior of workers were also obtained through interviews and observations.

Those companies that expressed interest in participating were initially screened by a team of trained researchers during preliminary site surveys. Permission was granted from one facility in each of the following plants: lead acid battery recycling, lead acid battery manufacturing, leather tannery, pharmaceutical, paint manufacturing and welding. These facilities were geographically located in a large industrial area, approximately 7 kilometers from Nairobi City Center that covers an area of 154 km². The companies operated on three shifts of eight hours each. Three hundred permanent workers (N=300) in production areas within these six facilities, who were requested to participate in this study, gave informed consent prior to their inclusion. The number of workers who were involved in this exercise was however 233, representing 77.7%.

Lung function examination and related respiratory symptoms

The age (years), height (metres) and body weight (kg) of each participant was determined prior to conducting the ventilatory function tests. Body mass index (BMI) was calculated as a ratio of body weight to height squared and expressed as kg/m². Lung function examinations were subsequently conducted using the spirometer, a ventilatory instrument (Vitalograph Alpha, Measuring Principle Flow Integration Serial No. AL 12308, Precision Syringe, Manufacturer Hans Rudolph Vol. delivered 3 L and Model No. 5530 Serial No. 553-23123). A pre-calibrated portable computerized spirometer was used to generate pneumotachographs, on the pneumoscreen, that were useful in assessing lung conditions of the participants.

During lung function examination, each participant sat comfortably on a chair and tight clothing was loosened. The medical officer demonstrated the procedure since this exercise depended on the participant's cooperation and effort. The participant took in the deepest breath until the lungs felt full, the breath was held and the lips were tightly sealed around a clean mouth piece of a spirometer. This air was blasted out forcefully and as fast as possible into a sensor until the lungs felt empty. The soft nose clips were used to prevent air from escaping through the nose. This procedure was repeated three times to ensure reproducibility of the results. The results were registered on pneumotachographs integrated with a microprocessor that measured flow rates. Forced vital capacity (FVC) and FEV1 in litres and percentages were recorded and the results were compared with predictive values based on age, sex and height of the participant [4].

Parameters of ventilatory function (FVC, FEV1, FEV1/FCV ratio and FEF25-75%) were assessed to determine obstructive, restrictive and combined patterns. These parameters were defined as follows: forced vital capacity (FVC) being the maximum volume of air that could be forcibly exhaled in one breath after a maximum inhalation [4]. A decrease in FCV was therefore an indicator of restrictive lung function, suggesting that the subject inhaled a reduced volume of air due to decline in total lung capacity. In contrast, forced expiratory volume of air in the first second (FEV1) was the volume of air exhaled in the first second of FVC manoeuvre. A reduction in the FEV1/FVC ratio therefore signified obstructive lung function in the large airway. However, a decline in forced expiratory flow between 25-75% (FEF 25-75%) of FVC or mid expiratory force indicates small airways obstruction.

Each of the participants was then interviewed by authorized medical personnel. The questionnaire considered information on personal habits

such as smoking of cigarettes and consumption of alcohols. Data on the medical history including medications and hospitalization, and related symptoms of the respiratory system in the recent past (preceding three months) were also captured [4,7]. The participants who were under medical treatment of tuberculosis, cancer, serious heart, lung or kidney complications were excluded from this study. The medical results of each participant was interpreted and recorded in a questionnaire.

Collection of urine and air samples

Standard procedures for collection, transport and storage of samples were also devised [9]. The collection of samples was carried out at a designated place within each factory site. Oral instructions on urine collection that focused on precautions against contamination were given prior to the sample collection [6]. Spot morning urine samples of 10 mL were provided by each of the participant in polypropylene tubes and were stored at -20°C prior to chemical analysis of Cr and Ni, and creatinine determinations.

Appropriate personal protective equipment including respirators was used by trained sampling technicians as a safety precaution against dust and fumes during sampling. Full-shift breathing zone samples were collected by the participants in their respective work areas using portable low volume air sampling pumps equipped with rechargeable batteries. Mixed cellulose ester membrane filters (0.8 µm pore size) were mounted in 37 mm diameter plastic cassette holders and attached to Tygon tubing that was connected to the sampling pumps. Each pump was calibrated in the field using a rotometer to a flow rate of 2.0 litres per minute. A personal air sampling pump was worn on the waist of each worker for the duration of the sampling period. The sample cassette was mounted on the collar in the breathing zone of each participant for a full eight-hour shift excluding breaks. Air sampling pumps were checked periodically in order to ensure a constant flow rate was maintained. All loaded filters and blank air and spot urine samples were transported to the Analytical Research Laboratory and stored using standard procedures prior to analysis [9].

Sample analysis

A flame atomic absorption spectrophotometer (FAAS)-AAS-Spectra AA1-10; (Varian-Techtron, Ltd., Vosendorf, Austria) was used to analyse airborne Cr and Ni. The commercial stock Cr and Ni solution from BDH-England (1000 mg/L) was used to prepare standard solutions. Analytical reagent grade chemicals supplied by Merk (Dermdent, Germany) were used throughout the analysis. Distilled and de-ionised water was used during the chemical analysis. All the glassware together with plastics were cleaned by soaking them overnight in 20% (v/v) nitric acid and then rinsed five times with deionised and distilled water, and thereafter dried in a clean oven at 65°C [10].

Air sample filters and field blanks, were subjected to slow wet acid digestion in accordance with the NIOSH standard analytical method 7024 [11]. Each sample solution was thereafter diluted with 0.1 M nitric acid to 10 mL in a volumetric flask prior to chemical analysis, using FAAS. Concentrations of airborne Cr and Ni were determined using FAAS following the NIOSH method 7024 [11]. Working standards for Cr and Ni were diluted appropriately in 0.01 M nitric acid (1% (v/v) as a stabilizer). Aqueous standard solutions with concentrations of Ni and Cr were run, which gave the required standard calibration curves. The concentrations of Ni and Cr in the digested breathing zone air samples were assayed in triplicates using FAAS at optimized operational conditions. This was subsequently obtained directly from the standard calibration graphs after correction of the absorbance for the signals from appropriate reagent blanks. Airborne levels of Ni and

Cr were expressed as micrograms (μg) per cubic metre (m^3) of air over an 8-hour Time Weighted Average (TWA).

Graphite furnace atomic absorption spectrophotometer (GFAAS; Buck Model 210 VGP Scientific, Inc., Norwalk, Conn) that was equipped with a hollow cathode Cr and Ni lamp and a deuterium arc background corrector was used to analyse urinary Ni and Cr. Certified reference samples of 2 levels procured from Belgium-LCG standards of Bureau Community Reference namely BCR™ 635-medium and BCR™ 636-high were used for validation of the analytical procedures [6].

Total chromium (Cr) and Nickel (Ni) standards were prepared from the commercial stock solution of 1000 $\mu\text{g}/\text{mL}$ in 0.01M nitric acid by successive dilution with distilled and de-ionized water. These standard solutions were subsequently used to generate the appropriate standard calibration curves. For Ni analysis, aliquots of 10 μL of the diluted spot urine samples were introduced directly into a pyrolytically coated graphite furnace tube with an equal volume of 10 μL matrix modifier mixture (0.6% m/v ammonium dihydrogen phosphate and 0.15% m/v magnesium nitrate in 0.01 M nitric acid) were automatically injected sequentially [6,9]. Similarly for Cr analysis, aliquots of 10 μL of the diluted urine samples were introduced directly into a pyrolytically coated graphite furnace tube and with an equal volume of 10 μL matrix modifier mixture (0.6% palladium nitrate and 0.15% m/v magnesium nitrate in 0.01 M nitric acid) were automatically injected sequentially [6,9]. The concentrations of Ni and Cr were obtained directly from the calibration graphs after automatic correction of the absorbance of the signal from appropriate reagent blanks.

Creatinine levels were analyzed in all spot urine samples using the alkaline picrate method, which was based on a modified Jaffe reaction [12]. This was carried out to normalize metal concentration in urine due to biological variations in volume. The amount of the complex formed was directly proportional to the concentrations of urinary creatinine at 500 nm [12]. A commercial creatinine standard solution was used to generate the required calibration curve. The levels of creatinine in each of the spot urine samples were obtained directly from this standard calibration curve after correction of the reagent blanks. Spot urine samples that had levels in g/g creatinine per litre of urine below 0.3 (dilute urine) or exceeded 3.0 (concentrated urine) were excluded from the analytical determination of Cr and Ni [12].

Quality control and assurance

Samples were analysed using adequate quality control procedures to ascertain reliability of the results. The reagents that were used throughout the analytical procedure were of high purity analytical grade. The main instrumental parameters for flame absorption atomic spectrophotometer (FAAS) and graphite absorption atomic spectrophotometer (GFAAS) were optimized separately for each metal. Reliability and accuracy of the method was determined by analyzing two levels of certified reference samples BCR™ 635 and BCR™ 636.

Quality control was also assured by inter-laboratory comparison of the levels of Ni and Cr in 10 sets of representative breathing zone air and urinary samples that were randomly selected and analyzed using FAAS and GFAAS at both the Mines and Geological Analytical Laboratory and at the Good Manufacturing Practices (GMP) Laboratory in Kenya. The range of linearity was also evaluated by checking the linear regression coefficient (r^2) of calibration values. It was considered acceptable when r^2 was 0.995 or higher. The validity of the method was further ascertained by cross method checks and replication analysis. All quality control samples were analyzed in triplicates and the average was

taken when the relative standard deviation (RSD) was less than 7% for consistency of the results.

Data Analysis

Results on spot urine and breathing zone air samples for each participant were coded and statistical analysis performed using the Statistical Package for Social Sciences program (SPSS-17.0). Assumption of normal distribution for continuous variables was tested by Kolmogorov-Smirnov test. Urinary metal levels of total Cr and Ni were expressed as microgram per litre ($\mu\text{g}/\text{L}$) of urine, whereas urinary creatinine levels were in grams per litre (g/L) of urine. The levels of Ni and Cr in spot urine samples were subsequently normalized and expressed as metal concentrations in microgram per gram ($\mu\text{g}/\text{g}$) creatinine. One-way analysis of variance (ANOVA) and the student t-test were used for the comparison of means of Ni and Cr in different groups of variables as appropriate. The relationship between urinary Cr and Ni levels (dependent variable) and those of breathing zone air samples (independent variables) was tested by the Pearson's Product of Moment Correlation. Linear regression analyses were carried out where applicable to estimate the inter-relationships. Coefficient of determination values due to linear regression were also used for the significance of linear trends at 5% level of significance.

Results

Demographic characteristic of the workers

Table 1 summarizes the characteristics of production workers. All the production workers (N=233) who participated in this study were male with an average age of 36.1 years and a standard deviation (\pm) of 15.4. Their age was between 18 and 60 years, with an average duration of employment of 5.9 ± 4 years, ranging from 2 to 33 years. The average weight, height and body mass index (BMI) was 70.9 ± 14.3 kg, 171.8 ± 8.5 cm and 23.9 ± 3.6 Kg/m^2 , respectively. It was further established that the differences in their mean age, height, weight and BMI of production workers in each of the six facilities was not statistically significant ($P>0.05$). At the time of the study, it was also found that 16.3% (38 of 233) of the employees were habitual smokers and smoked consistently at their workplace. Approximately 71.1% (166 of 233) of the production workers stated that they had never smoked. The rest (12.6%) were occasional smokers.

Manufacturing processes, working conditions and safety behavior of the workers

From the survey, it was established that all workers except those in the pharmaceutical plant were neither trained nor informed about working conditions and safety behavior, including associated adverse health risks due to exposures. In addition, none of the workers were provided with respirators, with the exception of those who were working in pharmaceutical, battery recycling and battery manufacturing plants. Further, those who had respirators were not wearing them appropriately and consistently, apart from those in the pharmaceutical facility. There were neither respiratory protection training programs nor personal hygiene education offered to the workers. For instance, all production workers except those in pharmaceutical facility were observed wearing their soiled work clothes while taking meals. There was also physical movement of these workers to non-contaminated areas such as the office and canteen, whereby they dispersed metal-containing dust. A risk of take home contaminated work clothes was apparent thereby exposing their family members including the environment to these contaminants.

Production areas	BR	W	BM	P	T	PA	Total
N (number of samples)	41	40	40	40	31	41	233
Parameters	35.7 ± 16.7	35.3 ± 16.6	36.6 ± 14.5	36.9 ± 14.8	34.8 ± 15.4	36.6 ± 14.5	36.1 ± 15.4
Mean age (years)							
Mean work duration (years)	6.0 ± 3.6	6.5 ± 3.6	6.0 ± 3.8	7.3 ± 4.3	4.5 ± 2.7	4.9 ± 2.0	5.9 ± 4.9
Mean body weight (Kg)	70.7 ± 15.7	74.3 ± 16.6	70.6 ± 13.2	70.9 ± 13.8	66.8 ± 12.4	69.9 ± 13.5	70.9 ± 14.3
Mean height (cm)	172.0 ± 9.0	169.8 ± 7.5	169.4 ± 8.6	173 ± 10.1	174.4 ± 7.5	173.0 ± 7.9	171.8 ± 8.5
Mean BMI (kg/m ²)	24.0 ± 4.6	24.5 ± 4.6	23.5 ± 3.8	23.9 ± 2.5	23.6 ± 3.7	23.7 ± 2.7	23.9 ± 3.6
Smoking status	70.5	68.5	72.0	86.3	60.7	68.0	71.1 (166)
(Non-smoker) No (%)							
(Habitual) Yes (%)	16.3	18.7	20.6	7.5	20.9	15.0	16.3 (38)
Mean FVC (L)	3.56 ± 0.9	3.27 ± 0.6	3.47 ± 0.5	3.67 ± 0.6	3.10 ± 0.7	3.47 ± 0.4	3.44 ± 0.6
Mean FVC (%)	80.0 ± 11.6	69.9 ± 17.2	82.5 ± 10.3	81.7 ± 12.2	68.9 ± 18.3	79.0 ± 15.6	77.3 ± 13.4
Mean FEV ₁ (L)	2.98 ± 0.5	2.48 ± 0.6	3.09 ± 0.7	3.45 ± 0.4	1.91 ± 0.7	2.73 ± 0.6	2.81 ± 0.6
Mean FEV ₁ (%)	76.7 ± 13.2	52.8 ± 18.4	75.1 ± 12.7	77.6 ± 12.2	48.5 ± 13.9	69.5 ± 13.2	67.5 ± 13.9
FEF ₂₅₋₇₅ (L/S)	3.39 ± 0.5	2.67 ± 0.6	3.31 ± 0.7	3.44 ± 0.4	2.48 ± 0.5	2.86 ± 0.7	3.04 ± 0.6
Respiratory diseases (%)	19.5 (8)	40.0 (16)	17.5 (7)	10.0 (4)	38.7 (12)	36.5 (15)	26.6 (62)
Occupational asthma (%)	19.5 (8)	42.5 (17)	17.5 (7)	7.5 (3)	41.9 (13)	39.0(16)	27.5(64)
Bronchitis (%)	19.5 (8)	40.0 (16)	17.5 (7)	12.5 (5)	38.7 (12)	34.1 (14)	26.6 (62)
Wheezing (%)	17.1 (7)	37.5 (15)	12.5 (5)	10.0 (4)	32.3 (10)	29.2 (12)	23.2 (53)
Shortness of breath (%)	19.5 (8)	40.0 (16)	17.5 (7)	12.5 (5)	38.7 (12)	34.1 (14)	26.6 (62)
Sneezing attacks (%)	17.2 (7)	40.0 (16)	12.5 (5)	10.0(4)	38.7 (12)	29.2 (12)	24.0 (56)

Note: BR: Battery Recycling; W: Welding; BM: Battery Manufacturing; P: Pharmaceutical; T: Tannery; PA: Paint Manufacturing. Sample size= N between (in parenthesis)

Table 1: Demographic characteristics and incidences of respiratory diseases and associated symptoms among production workers.

Industrial plants	Production areas	Mean airborne levels (µg/m ³) ± SD			Mean urinary levels (µg/g creatinine) ± SD	
		N	Ni	Cr	Ni	Cr
	Lead acid battery recycling	41	3.6 ± 1.1	2.4 ± 0.7	4.4 ± 1.8	2.1 ± 0.8
	Lead acid battery manufacturing	40	2.7 ± 0.8	1.9 ± 0.5	2.8 ± 1.2	1.7 ± 0.7
	Tannery	31	3.8 ± 1.1	23.4 ± 11.6*	3.1 ± 1.1	35.2 ± 12.1*
	Welding	40	10.3 ± 4.3*	9.2 ± 2.9	28.4 ± 7.8*	24.7 ± 8.2
	Pharmaceutical	40	1.9 ± 0.7	1.4 ± 0.7	2.2 ± 1.2	1.6 ± 0.8
	Paint Manufacturing	41	5.9 ± 3.0	6.0 ± 2.7	14.6 ± 8.2	9.8 ± 5.3

*Levels of Cr and Ni that was significant with respect to the production areas in different types of plants.

Table 2: Mean airborne and urinary levels of total chromium and nickel across production sections in diverse industrial plants.

Most habitual smokers were observed smoking without first washing their hands despite the fact that there were designated smoking zones and provision of washing and bathing facilities in some plants. Majority of paint manufacturers (56%, N=23) and welders (48%, N=19) were further observed sweeping dry floors where they may have dispersed substantial quantities of Cr and Ni-containing particles into the breathing zone air. They applied techniques or work practises that had high potential of generating and releasing fine particles that became airborne. It was also observed that operations such as weighing, mixing, emptying and handling of chrome in powder form during the tanning processes, including burning in open of storage bags, may have had a high potential of dispersing Cr into the breathing air. Similarly, unloading from the trucks, weighing, mixing and handling of dry raw materials (pigments and dyes) in powder form, during formulation of paints, created significant emissions of fine particles that were observed on the surfaces and throughout the production areas. Furthermore, welding processes without use of exhaust system contributed to considerable emission of visible fumes in the air.

Airborne and urinary nickel levels in production workers

Mean (± standard deviation [SD]) 8-hour nickel (Ni) concentrations in the breathing zone air samples from production workers across the six investigated facilities is presented in Table 2. Nickel concentrations

in breathing zone air of welders (N=40) was highest with a mean of 10.4 ± 4.3 µg/m³ and it ranged from 3.1 to 17.2 µg/m³. There was a significant difference (P<0.05) between these concentrations among welders and the other production workers. This was followed by a mean concentrations of 5.9 ± 3.0 µg/m³ of the paint manufacturers (N=41), which was relatively high compared to the other facilities included in this study.

Urinary Ni levels had a similar trend as those of the breathing zone air, where mean concentrations of Ni in urine was 28.4 ± 7.8 ug/g creatinine and was significantly high (P<0.05) in the welders than the other production workers. This was also followed by paint manufacturers with a urinary mean concentration of 14.6 ± 8.2 ug/g creatinine. Approximately 51% (21 of 40) and 5% (2 of 41) of welders and paint manufacturers, respectively had levels that exceeded the established Biological Exposure Indices (BEIs) of 30 ug/g creatinine [1,13]. A strong significant positive correlation (r=0.89, P<0.01) was established between Ni in the breathing zone air and urine of all production workers (N=233).

Airborne and urinary total chromium levels in production workers

From Table 2, the mean concentrations of total Cr were in ascending order of 1.4 ± 0.7 µg/m³ in a pharmaceutical (N=40), 1.9 ± 0.5 µg/m³

in battery manufacturing (N=40), $2.4 \pm 0.7 \mu\text{g}/\text{m}^3$ in battery recycling (N=41), $6.0 \pm 2.7 \mu\text{g}/\text{m}^3$ in paint manufacturing (N=41), $9.2 \pm 2.9 \mu\text{g}/\text{m}^3$ in welding (N=40) and $23.4 \pm 11.6 \mu\text{g}/\text{m}^3$ in tannery (N=31) plants. Chromium concentrations in the tannery plant were significantly high ($P < 0.05$) than those in the other plants.

Similarly, the mean urinary total Cr content of $35.2 \pm 12.1 \mu\text{g}/\text{g}$ creatinine was highest among the tanners. This was also followed by $24.7 \pm 8.2 \mu\text{g}/\text{g}$ creatinine in the welders and $9.8 \pm 5.3 \mu\text{g}/\text{g}$ creatinine in the paint manufacturers. A significant difference ($P < 0.05$) was observed between total Cr concentrations in tanners and the other production workers. The mean concentrations of Cr in the urine of the tanners also exceeded the established BEIs of $30 \mu\text{g}/\text{g}$ creatinine [13]. About 71.0% (22 of 31) of the tanners and 27.5% (11 of 40) welders had urinary Cr concentrations that exceeded this limit.

Prevalence of respiratory diseases and associated symptoms

The results in Table 1 indicates that 26.6% of the production workers (N=233) had various respiratory diseases. The respiratory complaints were associated with one or more of following: wheezing, shortness of breath and sneezing attacks among other related symptoms in the recent past (proceeding 3 months). Welders (40.0%, N=16), leather tanners (38.7%, N=12) and paint manufacturers (36.5%, N=15) had higher incidences of respiratory diseases than those in the lead acid battery recycling (19.5%, N=8), lead acid battery manufacturing (17.5%, N=7) and pharmaceutical (10.0%, N=4) plants. The former had 4 times likelihood of suffering from respiratory diseases than those working in a pharmaceutical facility. In most of the reported cases occupational asthma was more prevalent among the welders (42.5%, N=17), tanners (41.9%, N=13) and paint manufacturers (39.0%, N=16) than any other respiratory complaints. Bronchitis was also a more rampant respiratory disease among these workers.

It was also found that 28.0% of production workers (N=233) had ventilatory function deficit (respiratory obstruction, airway resistance or both manifestations), which was detected by the spirometer. Among the afflicted workers 37.5% (N=15), 47.5% (N=19) and 48.4.6% (N=15) were tanners, welders and paint manufacturers, respectively. Of those had obstructive lung function 53.3%, (N=8) were paint manufacturers, 66.6% (N=10) were tanners and 68.2%, N=13 were welders. This type of lung function deficit was characterised by FEV1/FVC (ratio) of less than 70% and FCV of less than 80% [7]. In addition, respiratory obstruction and airway resistance were much severe in the examined cases, where 34.9% of welders and 40.9% of tanners were afflicted. Both severe and mild airway obstructions cases detected by a spirometer were more than those that were self reported in the questionnaire. Employees who had reduced lung function had significantly ($P < 0.05$) high mean levels of $6.4 \pm 4.4 \mu\text{g}/\text{m}^3$ Ni and $9.6 \pm 5.3 \mu\text{g}/\text{m}^3$ Cr in their breathing zone air when compared to those who were not affected ($3.9 \pm 3.2 \mu\text{g}/\text{m}^3$ Ni and $4.4 \pm 3.8 \mu\text{g}/\text{m}^3$).

Discussion

Variations in the concentrations of total Cr and Ni that prevailed in the breathing zone air across diverse industrial plants may be attributed to a combination of various factors. For instance, the use of chrome in the tanning processes may have contributed to the elevated levels that were found in the breathing zone air in the tannery. In particular, the work activities in the tanning, weighing and buffing areas could have contributed to the substantial concentrations of Cr in the breathing zone air of the workers. The physical mixing of chrome in the drums that was in powder form may have resulted in emissions of considerable quantities of Cr-containing particles. These areas were

ventilated naturally through open doors, windows and raised roofs. It was likely that the air drafts dispersed Cr-containing particles to nearby production areas causing slight deviations in the concentrations within the production areas. During buffing processes that involved polishing of the tanned leather in order to make it smooth resulted in emission of fine particulate matter of leather dust that was observed on the floor surfaces and breathing zone air.

Observations made in the production areas of welding plant, revealed that engineering controls and industrial hygiene were inadequate in controlling airborne Ni and Cr that prevailed. Welding processes, which involved joining of painted drums and other metal bars using acetylene gas torches generated substantial fumes in the entire production areas. The fumes were observed building-up in the workers' breathing zones instantly during welding processes. Natural ventilation was also provided through open doors and windows. The air drafts appeared to disperse these fumes to adjacent sections of these facilities. Moreover there was no local exhaust ventilation system in the production areas to capture these fumes.

The presence of Cr and Ni in breathing zone air of production areas of paint formulations were as a result of substantial emissions of fine particles dispersed in the raw material area during off-loading of dry supplies in powder form from the trucks. These particles seemed to attain their peak levels during physical processes such as emptying and mixing operations of raw materials and were further observed spreading to the entire production areas. In addition, ventilation was provided naturally through open doors, where the air drafts dispersed the dust to other the adjacent areas. Previous studies are in agreement with this study where ATSDR [14] revealed that constituents of Ni are usually used in formulation of automotive paints while lead chromate is commonly used to formulate decorative paint.

The elevated concentrations of Cr are associated with adverse health effects. The U.S. OSHA found it necessary to lower hexavalent Cr (VI) concentrations by more than ten-fold, from 50 to 5 microgram (ug) per cubic metre (m^3) of air over an 8-hour time weighted average [15]. The decision to lower the exposure limit levels is based on the findings that workers who are exposed to Cr (VI) encounter increased risks of significant health effects including lung cancer, asthma, nasal septum, ulceration and perforation of the skin [1-6,15].

The relationship between Cr and Ni in the breathing zone air and urine in all production workers (N=233) was established using Pearson correlation coefficient. A strong positive correlation ($r = 0.86$ Cr and $r = 0.89$ Ni, $P < 0.01$) was observed, suggesting that urinary Cr and Ni levels was directly influenced by the breathing zone air. The presence of Cr and Ni in the urine of the production workers may be due to contribution from the breathing zone air through inhalation since the coefficient of determination was $r^2 = 74$ and 79 for Cr and Ni, respectively. Previous studies are in agreement that controlling particles containing-Cr and Ni compounds is an effective way of preventing health risks that are associated with Cr (VI) and Ni among workers [15,16]. It was also found that the habitual smokers had accumulated significantly high ($P < 0.05$) concentrations of Ni and Cr, although they were few to provide a sufficient trend.

Overall, welders, tanners and paint manufacturers were not provided with respirators therefore inhalation was a major intake of Cr and Ni from the breathing zone of these workers. The average urinary Cr levels exceeded the established limit (BEIs) of $30 \mu\text{g}/\text{g}$ creatinine [13]. On the hand, 51.2% (21 of 40) and 4.9% (2 of 41) of welders and paint manufacturers, respectively had Ni levels that exceeded the established

limit (BEIs) of 30 $\mu\text{g/g}$ creatinine [13]. Nickel exposure that exceeds this limit is associated with serious Ni-related health effects such those of cancers, allergies and reduced pulmonary functions [1,2,5].

Production workers with high prevalence of respiratory diseases, in addition, had significantly elevated mean concentrations of $6.4 \pm 4.4 \mu\text{g/m}^3$ Ni and $9.6 \pm 5.3 \mu\text{g/m}^3$ Cr in the breathing zone air when compared to those who were not afflicted by these ailments ($4.9 \pm 3.2 \mu\text{g/m}^3$ Ni and $3.4 \pm 3.8 \mu\text{g/m}^3$ Cr). Earlier studies also revealed that Cr is usually absorbed directly in the lungs, where it penetrates easily into the cellular membranes [4]. The metal binds to the haemoglobin in the red blood cells hence it interferes with its oxygen carrying capacity thereby impairing the airways and subsequently resulting in the respiratory diseases. Additionally the results are in agreement with previous studies, which established that increased pulmonary impairments among 30.9% of the chrome-platers against 16.2% of the controls [4]. Nickel exposure has also been associated with shortness of breath and bronchial-asthma attacks among other respiratory diseases that were revealed [1,5,14].

Some of the workers with reduced lung function had also reported high incidences of obstructive lung diseases and airway resistance, which was indicated by occurrence of occupational asthma. This therefore suggests that employees who were exposed to chronic levels of Cr and Ni in the breathing zone air may have increased occurrences of obstructive lung diseases particularly the tanners and welders. The results of this study are supported by those of Rastogi et al. [4] who also observed reduced ventilatory functions among Cr-exposed workers. Previous findings in addition revealed increased development of bronchial infections and lung cancer risks among workers who were exposed to airborne Cr [1-6,16]. Chronic exposure to Ni and Cr in form of dust and fumes can irreversibly damage the lungs and cause chronic bronchitis, shortness of breath and obstructive airway resistance, and renal dysfunction [1].

The results have indicated that Cr and Ni is a risk factor where there are inadequate engineering controls, industrial hygiene and work practice, particularly in welders, tanners and paint manufacturers [12]. Previous studies by Chuang et al. [17] and Tawichascri et al. [18] have indicated that safety behaviours played a role in accumulation of airborne lead among workers. It is evident that combinations of poor work practices and safety behaviours among workers, and the limited training and education on safety procedures, may have immensely contributed to elevated levels of Cr and Ni in both the breathing zone air and urine that were measured in these facilities. It was further apparent that supervisors on site were more concerned about maximizing on production other than the occupational health and safety of the workers.

It should be noted that this study encountered some limitations as there were no appropriate control group to determine other contributory factors to respiratory problems. It is also not clear whether other chemicals used in the manufacturing processes may aggravate the respiratory problems apart from Ni and Cr exposure. In addition, we were able to determine total Cr in both workplace air and urinary samples and we found it difficult to analyse Cr (VI). However, we recommend that further research should distinguish Cr (III) from Cr (VI) because of greater toxicity of Cr (VI). Despite these biases our study was able to establish the extent of exposure to Cr and Ni among production workers and respiratory problems.

Conclusion

Periodical medical examinations are critical in monitoring the health

of workers in order to prevent respiratory ailments. It is necessary that welders, tanners and, to an extent, paint manufacturers among other establishments that use Cr and Ni in their manufacturing activities include pulmonary function tests in their medical surveillance. This will subsequently enable the early detection of respiratory obstruction and airway resistance disorders and the possible removal of the affected workers from their respective workplaces prior to chronic impairment. Other mitigation measures, such as the use of appropriate respirators and training programs, can also be integrated upon early diagnosis of respiratory ailments. In the absence of national standards for Cr and Ni, written guidelines and processes for implementation, monitoring and compliance alongside training programs and educative manuals on good work practices, safety procedures, appropriate respirator use and personal hygiene ought to be designed and developed in these industries.

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