An assessment of exposure to benzene, toluene and xylene in a group of South African petroleum refinery workers.

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Research Article

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Abstract

Biomonitoring of exposure to benzene, toluene and xylene (BTX) was conducted in a group of 29 petroleum refinery workers in South Africa. Post shift urine samples from 21 males and 8 females over a period of four years (2010 to 2013 inclusive) were received from one petroleum refinery. The samples were analysed using high performance liquid chromatography with diode array detection and liquid-liquid extraction followed by gas chromatography-mass spectrometry for phenol, o-cresol and methylhippuric acid which are biomarkers of exposure to benzene, toluene and xylene, respectively.

Benzene and xylene results were well within the recommended exposure levels with the exception of one worker in 2013 with an elevated phenol exposure level. A few workers (< 40%) were found to be randomly overexposed to toluene, with 17% of the workers exhibiting higher than the biological exposure index. No difference was observed in exposure with regard to age and gender ($p>0.05$), except in 2012 where females were more exposed to benzene than their male counterparts ($p=0.003$). Differences in exposure were found among the three exposure categories (low, medium and high exposure), for both xylene and benzene exposure in 2010 and 2011, respectively. Friedman's ANOVA showed that over the four years of monitoring, the workers were exposed to variable levels of BTX ($p < 0.05$).

Random individual overexposure to toluene and an anomaly for benzene were noted. Biomonitoring of petroleum workers and proper assessment of the health risks and planning for adequate health protection are highly recommended for this group of workers.

Introduction

Fuel oil (also known as heavy oil, marine fuel or furnace oil) is a fraction obtained from petroleum distillation, either as a distillate or a residue (1). Fuel oils are complex mixtures of aliphatic and aromatic hydrocarbons, particularly n-alkanes, branched alkanes, cycloalkanes, aromatics (benzene, alkylbenzenes, naphthalenes, and polycyclic aromatic hydrocarbons), olefins and asphaltenes (2). In addition, they may contain small amounts of heteromolecules containing sulphur, oxygen, nitrogen, organometals, and other elements as additives. Creosote is also produced as a by-product of high-temperature distillation of tar (from petroleum); it contains hundreds of different hydrocarbons, including phenols, cresols, toluene, naphthols, and tar acids and bases (3). Among these, phenol and phenolic compounds are among the most toxic (4, 5,). Petroleum refineries and petrochemical plants are therefore major sources of volatile toxic hydrocarbons in the environment (6).

Petroleum refineries operate mostly outdoors, handling huge quantities of raw oil, its distillates and other oil-based products. Continuous operation involves transfer of streams between units, sampling and maintenance which are tasks all associated with attendant stray leaks leading to exposure of personnel to petrochemicals and associated hydrocarbons (7, 8, 9). Dermal contact and inhalation are two major pathways of exposure for industrial workers where fuel oils are produced or used hence adequate personal protection equipment (PPE), such as gloves, boots, coveralls, or other protective clothing are mandatory. Workers in this industry have been known to suffer from a wide range of disease conditions involving virtually all body organs and systems, including those of the lungs, endocrine, kidneys, liver, blood and central nervous system (10, 11).

Guidelines for chemical monitoring strategies have established that monitoring is necessary if there is reason to believe that a hazard exists or may develop in the workplace (12, 13), such as is the case for the petroleum refinery in this study. The aim of the study was to identify and quantify exposure to selected known mutagens and suspected carcinogenic agents, benzene, toluene and xylene, in a group of South African petroleum refinery workers, in order to provide exposure information for biomonitoring.

Methodology

2.1. Ethics

The Human Research Ethics Committee of the University of the Witwatersrand approved this research protocol (protocol reference number M1909100). Following ethics clearance, permission was granted to access the required patients' records from the National Health Laboratory Service (South Africa) data warehouse.

2.2. Background information and the study population

This was a retrospective, longitudinal study, in which demographics and background information were obtained from test request forms sent to the laboratory. Similarly, job categories of the petroleum refinery workers were defined based on information furnished on test request forms (Table 1). The study sample consisted of 29 employees, comprising 21 men (30 to 65 years old) and 8 women (32 to 57 years old).

The results of tests performed for samples received over a period of four years (2010 to 2013 inclusive) were retrieved from records of analyses performed by the laboratory (Table 2). The data/results were then recorded on a Microsoft Excel spreadsheet and analysed using descriptive, qualitative and quantitative statistics.

Table 1: Characteristics of the study population and job categories assigned based on information furnished to the laboratory on test request forms.

2.3. Method validation

The tests used for the analyses were validated using certified reference materials; Recipe™ Clinchek urine control, levels 1 and 2 (xylene & toluene exposure) and BioRad™ Lyphochek urine metals control, levels 1 and 2 (benzene exposure). The following figures of merit, i.e., accuracy, precision, limit of detection, limit of quantitation and uncertainty of measurement were determined prior to sample analysis (results not shown).

2.4 Sample Analysis

Post shift urine samples (20 ml) were received and stored at -20 °C until analysis. The samples were then analysed for phenol, ortho-cresol and methylhippuric acid as biomarkers of exposure to benzene, toluene and xylene respectively. The results were corrected for urinary creatinine. Urinary BTX levels were determined using liquid-liquid extraction followed by gas chromatography (Agilent™ 7890A system) coupled to mass spectrometry (Agilent™ 5975C) detection (GC-MS), and Agilent™ 1100/1200 Series high performance liquid chromatography (HPLC) for separation and Agilent™ Diode Array for detection (DAD) with specifics of each test described below;

2.4.1 Determination of phenol and o-cresol in urine

The conjugated (glucuronide/sulphate) forms of phenol and *o*-cresol were hydrolysed by acidifying urine samples with 60% perchloric acid (Associated Chemical Enterprises, South Africa) and 32% hydrochloric acid (Merck, Germany), and heating at 100 °C on a heating block. The liberated phenol and o-cresol were extracted with 98.9% diisopropyl ether (Sigma Aldrich, Germany) and analysed by Agilent™ GC-MS with 2,4-dimethylphenol (98%, Sigma Aldrich, Germany) used as an internal standard.

2.4.2 Determination of methylhippuric acid in urine

Urine specimens were filtered through a syringe-driven 0.22 µm filter unit and passed through the Phenomenex Synergi™ 4u Fusion (RP 80, 150 x 4.60 mm) HPLC column for separation of the analytes. The analyte, methylhippuric acid (MHA) was identified by HPLC using Agilent™ 1200 Series diode array detector.

2.5 Statistical Analysis

Results were analysed using STATISTICA™ v13.0 (TIBCO Statistica Ltd, Palo Alto, CA, USA), with the Shapiro-Wilk test used to determine the distribution of the obtained data (normality test). Friedman's ANOVA was used to evaluate if the BTX exposure levels were constant throughout the four-year period, and the Wilcoxon test determined the difference in BTX exposure levels between the years. In addition, non-parametric tests (Kruskal-Wallis and Tukey post hoc test) were used to determine and evaluate the relation between different factors (age, occupation and gender) and BTX exposure.

Results

Table 2 below, indicates the results of urine analysis for each test request received by the laboratory. The possibility of exposure of the study population to fuel oils as hazards in the petroleum refinery was determined by the relevant urinary biomarker content.

Table 2: The results of the various urine tests (phenol, *o*-cresol and methylhippuric acid) from the petroleum refinery

3.1 Phenol in urine

Throughout the four-year monitoring period (2010 to 2013) none of the workers exceeded the safe phenol level of 50 mg/g creatinine, except for only one individual (Table 2). Measured urinary phenol ranged from 0.2 to 30 mg/g creatinine, with the exception of one worker in 2013 who had urinary phenol of 76.60 mg/g. This individual worked at the transport workshop, probably repairing and servicing vehicles as indicated in Table 1.

3.2 *o*-Cresol in urine

Compared to non-exposed persons, majority of the workers (17 workers, approx. 59%) were found to be randomly overexposed to toluene over the monitoring period, and of these, 17% (5 workers) had results above the biological exposure index (BEI) of 1 mg/g creatinine. These individuals that were highly overexposed above BEI belonged to one of the following job categories; artisan, branch manager, cleaner, process controller, fitter and chemist. Of note is the fact that the branch manager and the cleaner whose jobs are both categorized as of low exposure were among the five individuals whose results were above the BEI (Table 3).

3.3 Methylhippuric acid in urine

In this group of refinery workers urinary MHA varied from as low as less than 0.01 mg/g creatinine to as high as 246.9 mg/g creatinine randomly throughout the four years of monitoring. Although the results were well below the BEI, most workers showed to have had some kind of exposure as they had results above 12 mg/g, which is the value set for unexposed persons (see Table 3).

Table 3: Chemical exposure levels believed to be safe for workers (16).

3.4 Data Analysis

The workers were classified based on their age, gender (male/female) and job exposure category as indicated in Table 1. The group classifications were as follows; ≤ 40 years, ≤ 50 years and > 50 years for age; and low, moderate and high for job exposure category.

The data showed a non-parametric distribution, therefore non-parametric tests were used to determine and evaluate the relation between different factors (age, occupation and gender) and BTX exposure and/or urinary BTX metabolites (Tables 4 & 5).

The Kruskal-Wallis test (ANOVA) showed that there was no significant difference with regard to BTX exposure among the different gender and age groups ($p \geq 0.05$), except in 2012 where females were more exposed to benzene than males ($p=0.005$). The difference in exposure categories was observed for benzene in 2010 and xylene exposure in 2011 ($p < 0.05$). In addition, Friedman test showed that all the workers were generally exposed to variable and/or different levels of BTX over the four years of monitoring. No significant difference was observed among the various groups with regard to urinary *o*-cresol content.

Table 4: Comparison of urinary phenol levels among the petroleum refinery workers in the low, moderate and high benzene exposure job categories using the Tukey-Kramer post-hoc test.

Table 5: **Results of the comparison of urinary methylhippuric acid levels among workers in the low, moderate and high xylene exposure job categories using the Tukey-Kramer post-hoc test.**

Discussion

Benzene, toluene and xylene (BTX) are major volatile hydrocarbons emitted during petroleum refinery operations, and all three chemicals are at least suspected carcinogens and mutagens (10, 17, 18). The major process streams in petroleum refining are associated with higher BTX content, and thus pose significant exposure risk to workers in these tasks (1). Consequently, jobs and tasks were categorized in this study according to their associated highest potential contact with refinery product streams containing BTX. Based on job descriptions workers were divided into high, moderate, and low-exposure categories. However, on closer examination, during any of the four years of monitoring, some of the workers in both the low and moderate exposure categories had very high exposures for all the BTX chemicals, even exceeding levels of some individuals in the high exposure job group.

Workers of all age groups in the refinery are at risk of exposure to BTX ($p < 0.05$), however exposure to xylene was significantly elevated in 2012 with an increase of between 70% and 129%. This increase was clearly due to an occupational incident (chemical spill, new raw material, type of crude oil/gasoline, etc.) since all workers' exposure to xylene (as shown by an increase in its metabolite, methylhippuric acid, in urine) increased twofold from 2011 to 2012. In 2013, there was a decrease in urinary methylhippuric acid across all job categories.

The results also suggest that both men and women generally have the same exposure risk with regard to BTX in this petroleum refinery. However, an increase in exposure to xylene was observed in 2011 where women showed exposure difference of approximately 60% higher than their male counterparts compared to all the other years where men were more exposed. The reason for this significant difference in xylene exposure could be from the fact that there were fewer women than men in the study. The results could thus be showing statistical bias and/or it could also be due to the fact that in most cases men and women have different lifestyle habits (e.g., heavy smokers and drinkers, etc.) as confounders.

Although there was no significant difference between men and women with regard to toluene and xylene exposure, in 2012 a difference in exposure to benzene was observed between men and women. In the four years of biomonitoring, women showed increased levels of exposure to benzene and toluene compared to men. The difference in benzene exposure between men and women in 2012 happened to be from an individual worker (process controller) whose benzene exposure levels increased rapidly (Table 3) compared to all other workers. The increase could have been due to either non-occupational factors (e.g., contaminated food, newly painted/renovated house, etc.) or occupational factors like chemical spills, or improper use of personal protection equipment while on duty. This individual's increased exposure led to general increase in average exposure to benzene for women while there was a decrease in average exposure for men (2011 to 2012), which then resulted in the significant difference in exposure compared to the other years.

However, generally there was no significant difference ($p \geq 0.05$) in toluene exposure with regard to the different occupations assessed in the study, with all job categories in the refinery having the same risk of being exposed to toluene. Also, all the workers in the different occupations, within the different exposure categories in the refinery had the same risk of exposure to benzene ($p \geq 0.05$), except in 2010 where high and moderate exposure job categories showed a difference in benzene exposure ($p < 0.05$). This suggests that levels of benzene that workers in these two categories were exposed to were not the same; which could be either from an occupational setting or non-occupational factors.

For 2010, 2012 and 2013 all the workers from the different job roles in the refinery had the same risk of exposure to xylene, but in 2011 there was a difference in exposure between the different job categories. The difference observed was from the workers in the moderate exposure category (Table 5) and this increased exposure is evident throughout all the four years of biomonitoring, except only in 2012 where the high exposure job category workers were highly exposed (Table 3). The xylene levels of exposure in the plant seem to have been constant in the four years with an overall average decrease of 7%, while exposures to toluene and benzene have an average increase of 146% and 260%, respectively.

In all the four years of biomonitoring in this petrochemical refinery, there has been an increase in benzene exposure, as observed from the analysis of its biomarker in urine, phenol, which is not the case for xylene (methylhippuric acid in urine) and toluene exposure (*o*-cresol in urine). This is probably due to its higher stability in the environment with a lifespan estimate of a couple weeks compared to 2 days for toluene and several hours for xylene (19, 20, 21). The decrease in xylene exposure throughout the four years could have also been influenced by time of urine collection, which was not necessarily constant for all participants.

There are a number of factors, both occupational and non-occupational that may contribute to elevated levels of exposure to BTX or the presence of BTX metabolites in urine. Non-occupational factors that may contribute to BTX exposure are smoking cigarettes, diet (fish, nuts, alcoholic drinks, poultry and offal); paint and consumer products (glues, adhesives, lacquers, waxes, detergents and cleaning products); traffic intensity (car exhaust emissions, type of fuel, age and type of motor vehicle, speed rate). Petrol stations, electronic devices (printer/photocopiers), some furniture (chair/tables) and infrastructure at new buildings also emit BTX s (22, 23).

Worker exposure to BTX was monitored at the petroleum refinery in this study, probably due to legislation amid growing concerns over the years based on cancer incidence data gathered in epidemiological studies of petroleum refinery workers (24). Based on the results for benzene exposure, measured as urinary phenol, it was generally assumed that there was no significant risk for this group of workers throughout the four years of continuous monitoring. On the other hand, some workers were significantly exposed to high levels of toluene, measured as urinary *o*-cresol. The sporadic individual overexposure to benzene and toluene in this refinery could be attributed to single chemical incidents. Workers at highest risk of significant exposure to BTX were those workers at the helm of production streams and maintenance tasks.

Conclusion

While the long-term or repeated worker exposure to hydrocarbons is unavoidable in a petroleum refinery, the combined health effects that could result from long-term exposure to multiple toxic chemicals, especially in female workers must be noted and addressed. Biomonitoring of these workers and proper assessment of the health risks and planning for adequate health protection to help minimise incidents and exposure are highly recommended. In addition, the highly toxic chemicals encountered in this work environment necessitate immediate improvement in engineering controls coupled with constant vigilance as part of an occupational health program aimed at providing scientific basis for decisions aimed at minimising exposure and the protection of worker health. Some of the measures recommended to mitigate workplace exposure could include reducing working hours and encouraging workers to regularly and properly use PPE and adopt proper hygiene.

Declarations

Availability of Data and Materials

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors' Contributions

BD performed data collection and analysis, interpretation of the results and writing of the first manuscript. PM assisted with results interpretation and wrote the manuscript; BK wrote, reviewed, edited the manuscript, and supervised the team. All authors contributed in the finalization of the manuscript.

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Tables

Tables 1-5 are in the supplementary files section.

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