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Comparison of Urinary PAHs among Firefighters and Asphalt Pavers

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by

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Dedication

I dedicate my thesis work to my wife, Dr. Jennifer Aquino. Jenny has made countless sacrifices to support my dreams and professional development. She selflessly moved away from her family and hometown of Miami to be with me while I served in the Navy. We persevered through multiple deployments and upon fulfilment of my military obligation, we relocated to Tampa so that I could complete medical specialty training in occupational medicine. Balancing clinical work, demanding graduate school responsibilities, parenthood and a marriage has been the greatest challenge of my life. Although it has been a struggle at times, I know the next chapter of life will be better because of our tireless efforts.

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Abstract

Firefighters and asphalt pavers are exposed to polycyclic aromatic hydrocarbons (PAHs) during various work activities. The purpose of this study was to evaluate urinary PAH levels and compare these bio-monitoring levels among firefighters, asphalt pavers, and non-occupationally exposed individuals. The National Institute of Standards and Technology (NIST) urinary PAH levels were used for non-occupationally exposed controls. When compared to the NIST standard for smokers and non-smokers, firefighters demonstrated statistically significant differences in urinary concentration differences for the following metabolites: 2-OH-fluorene, 3-OH-fluorene and 1-OH-pyrene, which were lower in firefighters than the NIST mean for smokers. 1-OHphenanthrene, 2-OH-phenanthrene and 3-OH-phenanthrene were higher among world trade center exposed firefighters than the NIST mean for smokers. When firefighters were compared to the NIST non-smoker standard, firefighters demonstrated elevated levels in all tested PAH biomarkers due to a mixture of smokers and non-smokers in the firefighter cohort.

Asphalt workers had statistically significant higher urinary concentration elevations in 2OH-fluorene, 1-OH-phenanthrene and 3-OH-phenanthrene as compared to the NIST smoker mean. When asphalt pavers were compared to the NIST non-smoker mean, asphalt pavers had statistically significant increases in all tested PAH biomarkers, with the exception of 2-OHphenanthrene. While firefighters did not demonstrate a substantial change in urinary PAH metabolite levels compared to control populations of smokers and non-smokers, asphalt pavers experienced concentrations that were in some cases increased by orders of magnitude compare to

NIST controls. Future research may be needed to evaluate any potential health risk posted to occupational exposed asphalt pavers.

Introduction

Cancer amongst firefighters is an international topic of interest. Politically, the topic is of great importance since organizations who represent firefighters, including the International Association of Fire Fighters (IAFF) and the National Fire Protection Association (NFPA), regularly lobby for legislation to make firefighter cancers presumptively related to occupational exposure. Awareness that cancer was a potential occupational hazard amongst firefighters became pervasive during the 1990s. In 1994, a retrospective cohort study was conducted with 5,995 subjects from Toronto area fire departments. It found that firefighters experienced increased risk of death from cancer of the brain and suggested increased risk for various other causes of death[1]. In the 2000s, further studies were performed. In a 2001 mortality study of Philadelphia firefighters, it was observed that an increased mortality existed for cancers of the colon and kidney, non-Hodgkin's lymphoma and multiple myeloma[2]. In 2007, Guidotti evaluated causality in selected cancer categories for firefighters using the criteria applied in tort litigation and workers compensation. He reported that an association between firefighters and certain cancers existed: bladder, kidney, testicular, brain, and lung cancer among non-smokers. NonHodgkin lymphoma, leukemia and myeloma cancers also merited an assumption of presumption. His conclusions, however, are not consistent with contemporary epidemiological firefighter data. In the Nordic study, in which a total of 16,422 male firefighters were included in the final cohort, a moderate excess risk was seen for all cancer sites combined[4]. More recently, a

2015 study that investigated exposure-response relationships for select cancer and non-cancer health outcomes in a cohort of US firefighters from San Francisco, Chicago and Philadelphia determined that lung cancer and leukemia mortality risks were modestly increased with firefighter exposures[5]. Cancer risk among firefighters is uncertain and available data is inconsistent. Additional research is required to accurately determine cancer risks.

Firefighters are exposed to an array of compounds, including polycyclic aromatic hydrocarbons (PAHs)[6]. Firefighters are not only exposed to PAHs during fire suppression operations, but also when conducting overhaul of turnout gear and by living in contaminated fire houses[6].

PAHs are a class of organic compounds produced by incomplete combustion or highpressure processes[7]. PAHs often consist of three or more fused benzene rings composed of only carbon and hydrogen. There are 18 PAHs that are commonly produced during fires[8]. Of these, the World Health Organization's International Agency for Research on Cancer (IARC) classifies one as being carcinogenic to humans (benzo[a]pyrene) and eight others as being possibly or probably carcinogenic to humans[9]. Smoke contains particulate and gaseous phases, both of which contain PAHs[6].

When actively suppressing fires, firefighters typically wear protective ensembles that are compliant with NFPA standards and a Self Contained Breathing Apparatus (SCBA). Even when properly utilizing the aforementioned protective equipment, it has been demonstrated that firefighters absorb PAHs during fire suppression activities[8]. Asphalt, also known as bitumen, is primarily utilized in the United States for road paving and exposure is known to potentially cause DNA damage[18]. It contains a mixture of polycyclic aromatic compounds which leads asphalt pavers to be exposed to PAHs. PAH metabolites are accepted biomarkers for monitoring exposure to asphalt emissions[16,20] and urinary 1-OH-Pyrene has proven to be a favorable predictor of oxidative DNA damage, specifically in asphalt exposed workers[17]. Urinary PAHs in asphalt pavers is associated with both inhalation and dermal exposure[19], with dermal exposure being the primary route[11,15]. Scientific evidence exists to suggest that asphalt pavers have an excess risk of cancer, although it is not clear if the increased cancer risk is secondary to only asphalt exposure or a combination of asphalt, diesel oil, tobacco and tar exposure[11]. In 2015, Rhomberg et al. performed a robust investigation to examine quantitative risks for roofing workers exposed to asphalt. It was reported that epidemiology studies do not consistently report elevated risks, nor do they have sufficient exposure evidence or satisfactory control for confounders. As such, much of the existing data was deemed inadequate for dose–response analysis. When Environmental Protection Agency consistent time-to-tumor model methods were applied to quantify potential cancer risks, roofers (with both dermal and inhalation exposure to asphalt) had cancer risks within a range typically considered acceptable within regulatory frameworks[21]. As of 2014 there were approximately 58,000 asphalt pavers in the United States. Job growth is expected to be faster than average[22].

Objective: The purpose of this study was to evaluate urinary PAH metabolite levels and compare these bio-monitoring levels among firefighters, asphalt pavers and non-occupationally exposed controls.

Hypothesis: A hypothesis that firefighters would have elevated urinary PAH metabolite levels when compared to the NIST standards was adopted.

Research Questions:

1. Do firefighters have elevated urinary PAH metabolite levels as compared to the general smoking and non-smoking population (NIST standards)?
2. How do urinary PAH metabolite levels compare between firefighters and asphalt pavers?

Methods

In 2014, the National Institute of Standards and Technology (NIST) developed two new Standard Reference Materials (SRMs), SRM 3672 Organic Contaminants in Smokers' Urine (frozen) and SRM 3673 Organic Contaminants in Non-Smokers' Urine (frozen), which included polycyclic aromatic hydrocarbons (PAHs). This standard was derived by combining data from: NIST, the Centers for Disease Control and Prevention (CDC), and the Institut National de Santé Publique du Québec (INSPQ)[13].

In 2003, the CDC published a case control study which compared blood and urine specimens of firefighters who responded to the World Trade Center (WTC) disaster to firefighters who were not present at the WTC. Sampling occurred 3 weeks after September 11, 2001. A total of 110 potentially fire related chemicals were analyzed, including urinary PAH metabolites. The study had 318 WTC disaster exposed firefighters and 47 firefighter controls who were not at the WTC. Urinary PAH data was ultimately collected for four cohorts: control firefighters, firefighters who were present at the WTC collapse, firefighters who were present on WTC post-collapse days 1 and 2 but were not present at collapse, and special operations command firefighters[10].

In 2012, a study using urinary biomarkers of PAHs to guide exposure-reduction strategies among asphalt pavers was conducted. 480 urine samples were collected from 12 paving workers over 3 workdays during 4 workweeks. Preshift, postshift, and bedtime urine samples were collected and analyzed for 1-OH-pyrene; 1-, 2-, 3-, 4-OH-phenanthrene; 1-, 2-OH-naphthalene; and 2-, 3-, 9-OH-fluorene. Each of the 4 weeks represented a different exposure scenario: a baseline week (normal conditions), a dermal protection week (protective clothing), a powered air-purifying respirator (PAPR) week, and a biodiesel substitution week (100% biodiesel provided to replace the diesel oil normally used by workers to clean tools and equipment)[11].

Using the cumulative results from each exposure scenario, the average of each urinary PAH was calculated and used for comparative analysis with the CDC firefighter data (not including special operations command firefighters) and the NIST standards. A hypothesis that firefighters would have the same urinary PAH metabolite levels when compared to the NIST standards was adopted. Microsoft Excel was used to perform calculations and T-test was utilized for statistical analysis.

Results

When compared to the NIST standard for smokers and non-smokers, firefighters demonstrated statistically significant differences in urinary concentrations for the following metabolites: 2-OH-fluorene, 3-OH-fluorene and 1-OH-pyrene, which were lower in firefighters than the NIST mean for smokers. 1-OH-phenanthrene, 2-OH-phenanthrene and 3-OHphenanthrene were higher among world trade center exposed firefighters than the NIST mean for smokers. When firefighters were compared to the NIST non-smoker standard, firefighters demonstrated elevated levels in all tested PAH biomarkers due to a mixture of smokers and nonsmokers in the firefighter cohort. Asphalt workers had statistically significant higher urinary concentrations of 2-OH-fluorene, 1-OH-phenanthrene and 3-OH-phenanthrene as compared to the NIST smoker mean. The results of statistical analyses between firefighter and asphalt paver cohorts is summarized in tables 7-12.

Tables

Table 1. Results Summary of 2-OH-fluorene comparisons among cohorts and NIST standards

		Smoker standard (0.854 ng/g)		Non-smoker standard (0.105 ng/g)	
2-OH-Fluorene	Mean (ng/mL)	P value	Interpretation	P value	Interpretation
Contol firefighters	0.586754	3.2301E-83	Statistically lower	3.20544E-94	Statistically higher
Firefighters A*	0.631218	6.637E-235	Statistically lower	1.1586E-285	Statistically higher
Firefighters B**	0.6825	1.911E-263	Statistically lower	0	Statistically higher
Asphalt Pavers	1.49	6.7834E-06	Statistically higher	1.62747E-19	Statistically higher

Table 2. Results Summary of 3-OH-fluorene comparisons among cohorts and NIST standards

		Smoker standard (0.42 ng/g)		Non-smoker standard (0.0384 ng/g)	
3-OH-Fluorene	Mean (ng/mL)	P value	Interpretation	P value	Interpretation
Contol firefighters	0.253128	1.7326E-70	Statistically lower	3.40544E-75	Statistically higher
Firefighters A*	0.216393	2.529E-84	Statistically lower	8.19069E-82	Statistically higher
Firefighters B**	0.242954	6.0642E-85	Statistically lower	1.21907E-87	Statistically higher
Asphalt Pavers	0.56	0.31733679	Not significant	0.021716297	Statistically higher

Table 3. Results Summary of 1-OH-phenanthrene comparisons among cohorts and NIST standards

		Smoker standard (0.133 ng/g)		Non-smoker standard (0.0479 ng/g)	
1-OH-Phenanthrene	Mean (ng/mL)	P value	Interpretation	P value	Interpretation
Contol firefighters	0.164906	9.9757E-49	Statistically higher	6.10192E-73	Statistically higher
Firefighters A*	0.181871	3.7246E-64	Statistically higher	5.60143E-83	Statistically higher
Firefighters B**	0.202025	1.3095E-69	Statistically higher	1.3204E-84	Statistically higher
Asphalt Pavers	0.42	0.0504374	Statistically higher	0.013760436	Statistically higher

Table 4. Results Summary of 2-OH-phenanthrene comparisons among cohorts and NIST standards

		Smoker standard (0.0825 ng/g)		Non-smoker standard (0.0242 ng/g)	
2-OH-Phenanthrene	Mean (ng/mL)	P value	Interpretation	P value	Interpretation
Contol firefighters	0.130505	3.6835E-56	Statistically higher	5.49903E-71	Statistically higher
Firefighters A*	0.154251	5.5597E-71	Statistically higher	4.38962E-82	Statistically higher
Firefighters B**	0.187573	2.1432E-77	Statistically higher	1.23024E-85	Statistically higher
Asphalt Pavers	0.23	0.20360431	Not significant	0.110332894	Not significant

Table 5. Results Summary of 3-OH-phenanthrene comparisons among cohorts and NIST standards

		Smoker standard (0.123 ng/g)		Non-smoker standard (0.0271 ng/g)	
3-OH-Phenanthrene	Mean (ng/mL)	P value	Interpretation	P value	Interpretation
Contol firefighters	0.133099	1.2112E-30	Statistically higher	3.8004E-74	Statistically higher
Firefighters A*	0.155891	1.2478E-59	Statistically higher	4.18788E-85	Statistically higher
Firefighters B**	0.177834	2.7345E-69	Statistically higher	3.61752E-88	Statistically higher
Asphalt Pavers	0.45	0.02459616	Statistically higher	0.004555996	Statistically higher

Table 6. Results Summary of 1-OH-pyrene comparisons among cohorts and NIST

		Smoker standard (0.17ng/g)		Non-smoker standard (0.0299 ng/g)	
1-OH-Pyrene	Mean (ng/mL)	P value	Interpretation	P value	Interpretation
Contol firefighters	0.062417	1.3867E-69	Statistically lower	2.66448E-47	Statistically higher
Firefighters A*	0.092129	2.3245E-69	Statistically lower	3.55019E-65	Statistically higher
Firefighters B**	0.106306	2.5817E-65	Statistically lower	1.03898E-68	Statistically higher
Asphalt Pavers	0.55	0.06403632	Not significant	0.014650798	Statistically higher

Table 7. Results Summary of 2-OH-fluorene comparisons between firefighters and asphalt pavers cohorts

2-OH-Fluorene	P value
Control firefighters vs. Asphalt Pavers	1.56E-106
Firefighters A* vs. Asphalt Pavers	0
Firefighters B** vs. Asphalt Pavers	0
Ctrl.Firef vs. Firefighters A*	3.9318E-299
Ctrl.Firef vs. Firefighters B**	0
Firefighters A* vs. Firefighters B**	2.3894E-06

Table 8. Results Summary of 3-OH-fluorene comparisons between firefighters and asphalt pavers cohorts

3-OH-Fluorene	P value
Control firefighters vs. Asphalt Pavers	1.08951E-14
Firefighters A* vs. Asphalt Pavers	0
Firefighters B** vs. Asphalt Pavers	0
Ctrl.Firef vs. Firefighters A*	7.058E-247
Ctrl.Firef vs. Firefighters B**	6.5582E-192
Firefighters A* vs. Firefighters B**	0.118476817

Table 9. Results Summary of 1-OH-phenanthrene comparisons between firefighters and asphalt pavers cohorts

1-OH-Phenanthrene	P value
Control firefighters vs. Asphalt Pavers	1.04151E-24
Firefighters A* vs. Asphalt Pavers	0
Firefighters B** vs. Asphalt Pavers	0
Ctrl.Firef vs. Firefighters A*	4.4437E-239
Ctrl.Firef vs. Firefighters B**	0
Firefighters A* vs. Firefighters B**	0.08809833

Table 10. Results Summary of 2-OH-phenanthrene comparisons between firefighters and asphalt pavers cohorts

2-OH-Phenanthrene	P value
Control firefighters vs. Asphalt Pavers	2.02227E-06
Firefighters A* vs. Asphalt Pavers	0
Firefighters B** vs. Asphalt Pavers	0
Ctrl.Firef vs. Firefighters A*	2.4757E-274
Ctrl.Firef vs. Firefighters B**	0
Firefighters A* vs. Firefighters B**	0.001757247

Table 11. Results Summary of 3-OH-phenanthrene comparisons between firefighters and asphalt pavers cohorts

3-OH-Phenanthrene	P value
Control firefighters vs. Asphalt Pavers	6.3959E-35
Firefighters A* vs. Asphalt Pavers	0
Firefighters B** vs. Asphalt Pavers	0
Ctrl.Firef vs. Firefighters A*	1.9564E-284
Ctrl.Firef vs. Firefighters B**	0
Firefighters A* vs. Firefighters B**	0.047169349

Table 12. Results Summary of 1-OH-pyrene comparisons between firefighters and asphalt pavers cohorts

1-OH-Pyrene	P value
Control firefighters vs. Asphalt Pavers	1.23012E-39
Firefighters A* vs. Asphalt Pavers	0
Firefighters B** vs. Asphalt Pavers	0
Ctrl.Firef vs. Firefighters A*	2.1247E-301
Ctrl.Firef vs. Firefighters B**	0
Firefighters A* vs. Firefighters B**	0.258521634

<u>Figures</u>

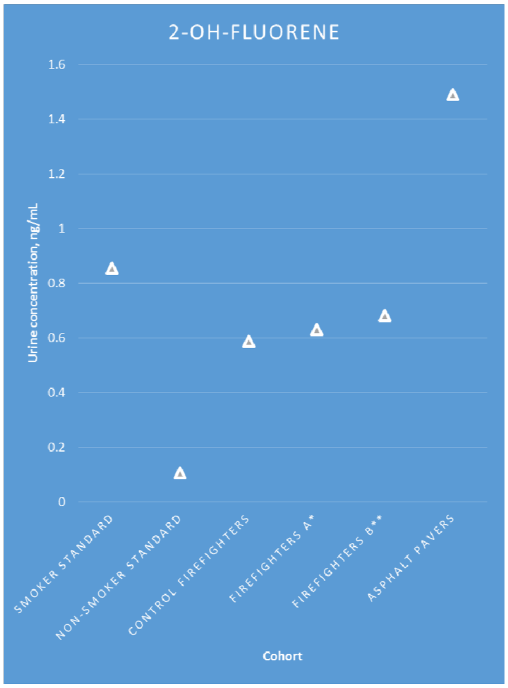

Figure 1. Histogram depicting mean urine concentrations of 2-OH-Fluorene among cohorts and NIST standards.

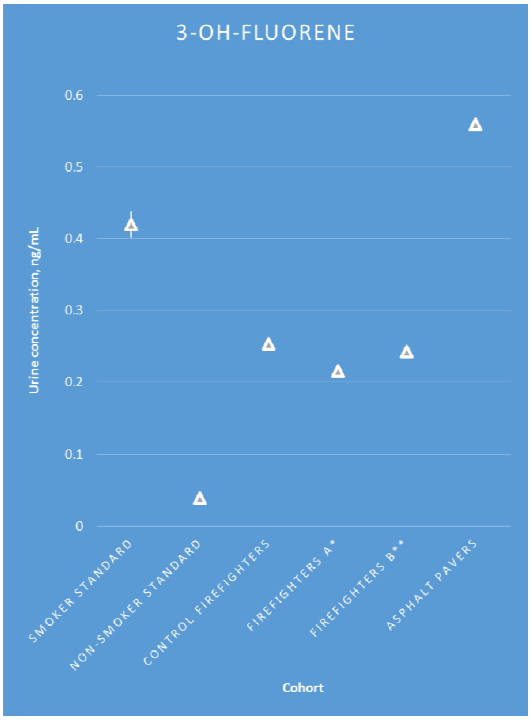

Figure 2. Histogram depicting mean urine concentrations of 3-OH-Fluorene among cohorts and NIST standards.

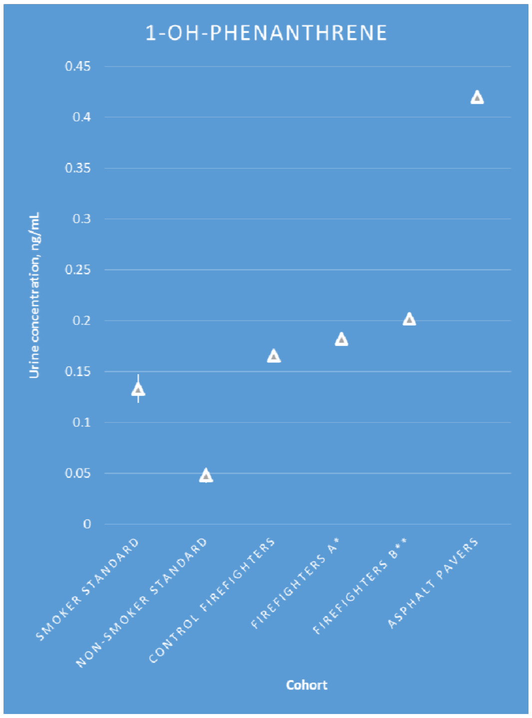

Figure 3. Histogram depicting mean urine concentrations of 1-OH-Phenanthrene among cohorts and NIST standards.

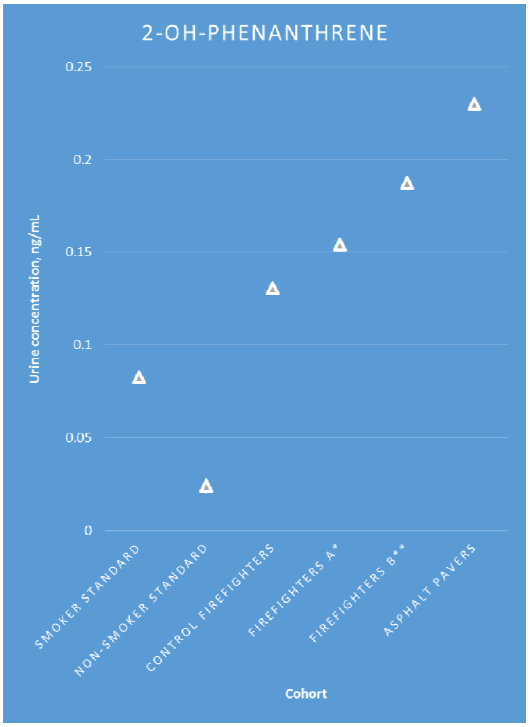

Figure 4. Histogram depicting mean urine concentrations of 2-OH-Phenanthrene among cohorts and NIST standards.

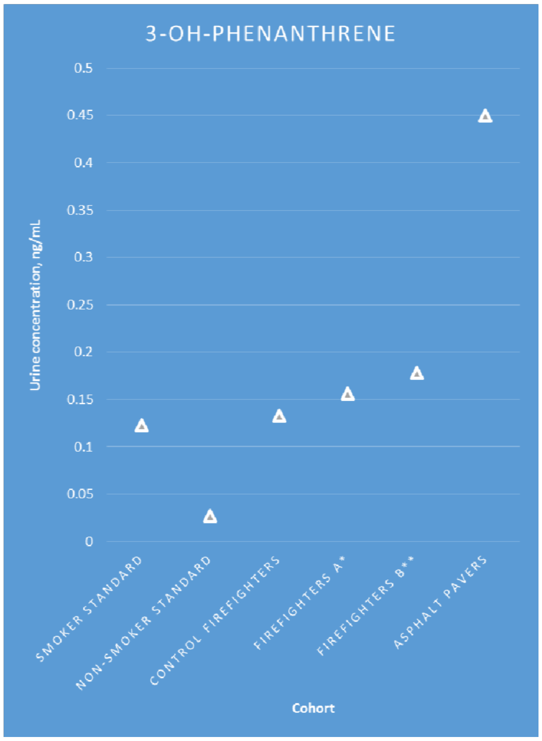

Figure 5. Histogram depicting mean urine concentrations of 3-OH-Phenanthrene among cohorts and NIST standards

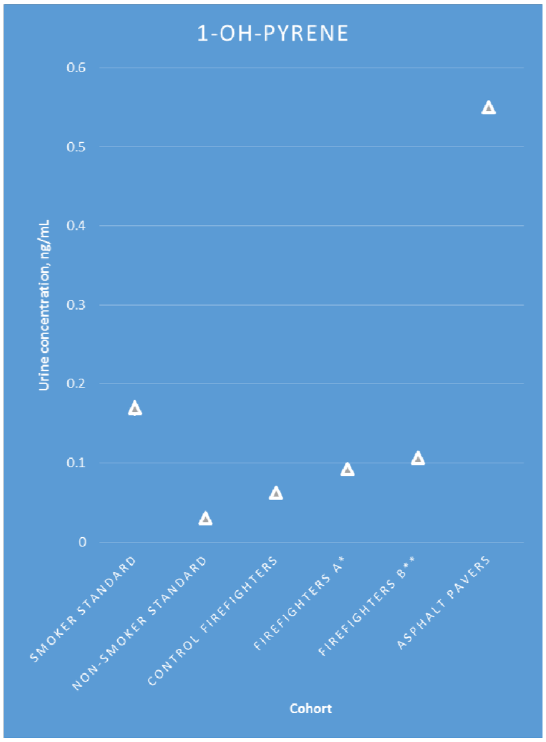

Figure 6. Histogram depicting mean urine concentrations of 1-OH-Pyrene among cohorts and NIST standards.

** Firefighters A represent those present at the WTC collapse.*
***Firefighters B represent those who were present on WTC post-collapse days 1 and 2 but were not present at collapse*

Discussion

Presumptive disability laws link a specific occupation with a disease or condition that has been shown to be a hazard associated with that occupation. By establishing an association, if an individual employed in the occupation covered by the presumption develops a disease or condition that is specified in the presumptive law, then that disease or condition is presumed to have come from that occupation. As such, the burden of proof shifts from the employee to the employer to establish that the condition was not in fact associated with the occupation but with an alternative cause.

Prior to 2002, no firefighter in the world was automatically covered for medical expenses related to presumed occupationally induced cancer. Now 90% of firefighters in Canada and Australia have some coverage along with firefighters in 33 US states[12]. As lawmakers continually debate whether or not to implement more presumptive legislation, a benefit that would cost an immense amount of tax payer funds, it is important to take into account the strength of all available scientific evidence as it relates to causality. Hill's criteria should be applied. There are ethical considerations both in caring for public servants who risk their lives in performing their occupational duties and in sensibly spending tax monies that continually become scarcer due to political and societal demands.

A potential for skewed urinary PAH levels secondary to the sample cohorts having a mixture of smokers and non-smokers exists. The firefighter cohort was composed of a mixture of both smokers and non-smokers. Using a serum cotinine greater than to 10 ng/mL to determine smoker status, 87 of the 358 (24.3%) firefighters with measured serum cotinine in the analysis groups were smokers. In the asphalt paver cohort, five of the workers were nonsmokers, six smoked cigarettes, and one was a smoker who quit during the study. One of the nonsmokers chewed tobacco[14].

When considering data to include in this investigation, a comprehensive literature search was performed. After using inclusion criteria of having: 1) specific occupational groups identified and 2) urinary PAH data that matched available NIST standards, data sets from the WTC firefighter study and the asphalt paver exposure-reduction study were ultimately used for comparative analysis. Available data sets that did not characterize sub-populations were excluded. The WTC firefighter study had notable strengths and weaknesses. The main strength of the firefighter study is that it is the most robust biomonitoring study ever done on any occupational cohort during the initial weeks of exposure to a major fire, building collapse or urban disaster[10]. Other key advantages of the study are the sheer number of compounds tested (110) and number of participant firefighters (318 exposed and 47 controls). The collaborative effort between CDC-NIOSH and the New York City Fire Department Bureau of Health Services ensured that data collection and medical monitoring were performed appropriately. Biomonitoring protocol to quantify chemicals in firefighter blood and urine was developed by the CDC's National Center for Environmental Health, Division of Laboratory Sciences, which further added to the validity of the study. It should be noted that the reason special operations firefighters were not included in this study is because raw data was not available from this cohort.

Biomonitoring data is ideal when collected in conjunction with measurements of external exposure. Since it is not feasible to perform personal sampling of external exposures during times of disaster, it would be unreasonable to consider this missing element a weakness of the study, although it should be discussed. The most obvious limitation of this study is that the biomonitoring measurements were made at only one point in time. If data could have been serially collected from the initial fire onward, that would have been advantageous for investigating chemicals with short half-lives.

Other issues to consider are the control group and exposures to substances not tested. The control group consisted of New York firefighters who had been placed on office duty, which may have limited their exposure to any recent fires. Substances such as asbestos, fiberglass, silicates and other inorganic particles are not subject to biomonitoring, so the study cannot provide insight into the potential effects of exposure.

In the asphalt paver exposure-reduction study, there were 480 asphalt paver urine samples which originated from only 12 workers. Since the urine samples were collected at different times of the day and after various methods of exposure mitigation, we used average urinary PAH concentrations in our analysis as it was not deemed necessary to perform separate analysis on each category of available asphalt paver urine. However, since three of the four study weeks featured samples from varying methods of exposure protection (not typically used in current dayto-day practice), there is potential for the urine PAH results to be skewed to lower concentrations. Although our analysis demonstrated various statistically significant elevations in urinary

PAH concentrations in both firefighters and asphalt pavers as compared to the general population (NIST standards), we cannot conclude that an increased risk of cancer for firefighters and asphalt pavers exists. Cancer is generally the result of chronic exposure and the data used in this study could be from acute or sub-chronic exposure. Furthermore, quantifiable urinary PAH levels that cause cancer do not exist.

Asphalt workers (and other occupations who do not currently have medical coverage through presumptive legislation, i.e. coke oven workers and diesel mechanics) do not possess the level of political influence that firefighters have. The results of this study makes evident that future research may be necessary to evaluate potential health risk for occupationally exposed asphalt pavers. Eventually, presumptive legislation laws for non-firefighter professions with elevated PAH contact could be deliberated.

The authors of this paper do not imply that risk is associated with PAH exposure. Our findings relate only to exposure levels. Furthermore, we do not imply that any statistically increased PAH metabolite levels equate to increased risk or clinical importance.

Conclusions

While firefighters did not demonstrate a substantial change in urinary PAH metabolite levels compared to control populations of smokers and non-smokers, asphalt pavers experienced concentrations that were in some cases increased by orders of magnitude compared to NIST controls. Future research may be needed to evaluate any potential health risk for occupationally exposed asphalt pavers.

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