Medicina Universitaria 2014;**16(64)**:136-140

MEDICINA UNIVERSITARIA

www.elsevier.com.mx

REVIEW ARTICLE

Health effects due to exposure to polycyclic aromatic hydrocarbons from the petroleum refining industry

M. T. Montaño-Soto, L. Garza-Ocañas*

Pharmacology and Toxicology Department, School of Medicine and "Dr. José Eleuterio González" University Hospital, Universidad Autónoma de Nuevo León, Monterrey, N.L., Mexico

Received: January 2014; Accepted: May 2014

KEYWORDS
Polycyclic aromatic hydrocarbons; Health; Health impact assessment; Petroleum; Oil refinery; Air pollutants; Environmental; Mexico.

Abstract
Introduction: Polycyclic aromatic hydrocarbons (PAH) are a group of semi-volatile organic compounds composed of 2 or more aromatic rings, generated during incomplete combustion of organic matter. These compounds have been considered as major air pollutants, and also, there is evidence of potential mutagenic and carcinogenic effects in some of them. One of the most important sources of these compounds is industry, and particularly, in processes such as aluminium or coke production, waste incineration and petrochemical and oil refining. This last process is the subject of this article, whose aim is to review the health effects in persons potentially exposed to PAH generated during petroleum refining.
Methods: A descriptive review of the available literature was performed, in which PubMed was used as an information source. The following search descriptors were used: refinery, PAH, health, health impact assessment, air pollutants and environmental, as well as their translations in Spanish.
Results: Eleven articles were included, and most of them correspond to epidemiological studies in which a high incidence of cancer is reported.
Conclusions: The reviewed studies concur that there is a significant relationship between the presence of oil refineries and the increase of adverse health effects of workers and people living in areas that are close to these industries, particularly, respiratory diseases and cancer. However, it is important to develop studies that simultaneously evaluate the effects on human health and the concentration of these substances in the environment, in order to establish a more direct relationship between the 2 variables.

* Corresponding author: Pharmacology and Toxicology Department, School of Medicine and *"Dr. José Eleuterio González"* University Hospital. 235 Gonzalitos Street, Mitras Centro, Z.P. 64460, Monterrey, N.L., Mexico. Telephone: (+52 81) 8329 4201.
E-mail address: logarza@live.com.mx (L. Garza-Ocañas).

Introduction

Evidence shows an increasing correlation between environmental pollution and health effects on an exposed population.[1] By the year 2006 the World Health Organization (WHO) estimated that between 23% and 24% of the world's morbidity/mortality was attributable to environmental factors, and of the considered conditions the ones associated with air pollution occupied 2nd place.[2]

Among major air pollutants representing health risks are polycyclic aromatic hydrocarbons (PAH), which can be found in the gas phase or well-bonded to particulate matter (PM).[3] PAHs are a group of semi-volatile organic compounds composed of 2 or more aromatic rings, generated during incomplete combustion of organic matter. During this process molecule and radical fragments are combined, thus creating these substances.[3] These compounds are major environmental pollutants because they are considered to be potentially carcinogenic and mutagenic, hence considered "air quality markers" in terms of the health risks their presence represents.[4-10]

According to the United States (US) Environmental Protection Agency (EPA), out of the 100 substances of this kind listed, 16 are catalogued as "priority pollutants" (Table 1) based on the following criteria: toxicity, human exposure potential and frequency of occurrence in hazardous waste sites.[9-11]

PAH presence in the environment

PAHs are generally found in the environment as complex combinations, practically in every substrate, their accumulation is the result of emission rates exceeding the capability of natural degradation.[12] They can be released into the environment through natural sources such as forest fires and volcanic eruptions; however in recent years anthropogenic emissions have been responsible for the increase of these substances in the environment. Among the main sources of anthropogenic origin are: domestic, mobile, agricultural and industrial emissions.[9]

Despite the fact that the industry in general is considered an important source of PAH emission into the environment, the activities that emit the largest PAH amounts are: primary aluminum production, coke production, waste incineration, fossil-fuel-based power generation, the petrochemical industry, and crude oil refineries.[9,10]

The refining industry as a PAH source

Undoubtedly oil refining's final products are currently one of the most important energy sources for the industry as well as for most people's everyday life. However, over the past few years, this activity has been strongly connected to the presence of high PAH concentrations in locations close to these types of facilities.[12-20] At most of these sites PAH levels have been quantified even above those reported at areas with major vehicular traffic.

Consequently, different authors have researched the health effects as a result of the exposure to this type of industry, in people exposed occupationally and environmentally. Thus the objective of this study is to conduct a descriptive review of the available literature in which they show the main health effects linked to PAH exposure from the oil refinery industry.

Methods

Available literature was identified performing a web search. We used PubMed's database as a source of information, as well as Science Direct, EBSCOhost and Springer, through the General Direction of Libraries of the *Universidad Autónoma de Nuevo León* (UANL, by its Spanish acronym). We used the following terms and combinations as search criteria (and their Spanish equivalents): oil refinery AND polycyclic aromatic hydrocarbons [MeSH] AND health [MeSH], oil refinery AND health [MeSH], OR health impact assessment [MeSH], oil refinery AND air pollutants [MeSH], OR environmental impact [MeSH], these last 2 combinations were used to examine the environmental PAH presence in areas located close to oil refineries. The search was not limited to newer articles, thus we used all available literature to date.

Results

We obtained a total of 87 articles, from which we selected 11. The excluded articles were those that did not evaluate sanitary effects of exposure during oil production or those where they evaluated the effects in other organisms (like in *Salmonella* in the "Ames Test"), or by other pollutant sources.

The articles where work exposure was evaluated correspond to 3 epidemiological studies developed for the purpose of correlating the increase in cancer incidence and work activity in refineries. They used work records, national survey demographic data, national cancer and epidemiological

Table 1 Substances prioritized for their carcinogenic and mutagenic potential.

Naphthalene	Fluoranthene	Benzo (a) pyrene*
Acenaphthene	Pyrene	Dibenzo (ah) anthracene*
Acenaphthylene	Benzo (a) anthracene*	Benzo (ghi) perylene
Fluorene	Chrysene	Indeno (123-cd) pyrene*
Phenanthrene	Benzo (b) fluoranthene*	
Anthracene	Benzo (k) fluoranthene*	

* Carcinogens.
Source: US Environmental Protection Agency (EPA).[10]

surveillance records from different countries. Of the studies that evaluated environmental exposure, 4 of them linked exposure and cancer incidence, 2 of them linked the distance to the refineries and cancer incidence, and one linked exposure with effects over gestation time and another one with pulmonary function in children. Table 2 is a list of the main findings in this review.

In 1991, in a study conducted in Australia by Christie et al., where they evaluated cancer incidence in the Australian oil industry from 1981 to 1989, observed an increase of approximately twice as many cases of cancer than expected in employees of the different oil companies operating in the country, including refineries, production facilities, warehouses and distribution centers. The most common cancer types were lung cancer and pleural cancer, which have been linked to PAH exposure, as well as non-Hodgkin lymphoma, multiple myeloma and leukemia, the latter of which has been mainly linked to benzene exposure. Benzene is also an aromatic obtained during oil refinery, however, this has the characteristic of being volatile, and this substance as well as PAHs have been strongly connected to cancer development.[21]

Similar results were presented by Järvholm et al., in Sweden, where a cohort study was conducted, including 4,319 Swedish workers (4,128 men and 191 women) who worked for at least one year in the oil industry. Cancer incidence within these workers was compared to cancer incidence within the general population, and in the results it was reported that refinery operators presented a statistically significant increment in the development of leukemia (6 cases vs. 1.7 expected, 90% confidence interval [CI] of relative risk) in comparison to the general population.[22]

On the other hand, in the year 2000, Wong and Raabe conducted a meta-analysis based on a review of 28 cohort studies, which included over 350,000 oil workers in countries like US, United Kingdom (UK), Canada, Australia, Italy, Sweden and Finland, during an observation period of 60 years (1937-1996). In their results a significant increase in the risks of melanoma in 2 studies in the UK stand out, and prostate cancer in a couple of studies in the US.[23]

For different authors it is reasonable to consider that if occupational exposure to the oil industry pollutants increases incidence of diseases in workers, then environmental and non-occupational exposure to these pollutants can also cause an increase in the incidence of certain diseases among residents of areas located close to this type of industry.[24-28] Under the same hypothesis several papers have been developed where they evaluate the effects in the open population who live in areas close to refineries. The results of some of these studies suggest an important connection between cancer incidence and the proximity to refineries.

Since the early 1980's in the US a study was conducted where they determined cancer incidence in places located close to a refinery along the coast of California. This study showed a growing and statistically significant trend ($p<0.05$) of cancer in the oral cavity and pharynx, stomach, trachea, bronchi, lung, prostate, kidney and urinary organs, in men, while in women they observed a statistically significant increase in oral cavity and pharynx cancer.[24]

In Taiwan, they evaluated if lung cancer mortality in women was linked with residence adjacent to an oil refinery. In this country lung cancer is the second cause of cancer mortality in men and the main cause for women. Results showed that women with a higher exposure to the petrochemical industry presented a higher risk of developing lung cancer in comparison to the group who lived in locations with low petrochemical atmospheric pollution.[25]

On the other hand, Barregard et al. conducted a study in Sweden, where they evaluated leukemia incidence in an area down-wind from a big oil refinery. In their results they observed an increase in leukemia incidence in the population living in sites affected by the winds from the refinery,

Table 2 Evaluated health effects.

		Health effects													
Author	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Christie	(1991)	X	X								X	X	X		
Järvholm	(1997)												X		
Wong	(2000)			X	X	X									
Kaldor	(1984)	X			X	X	X	X	X	X					
Yang	(1999)	X													
Barregard	(2009)												X		
Axelsson	(2010)	-								-	-		-		
Wilkinson	(1999)												X		
Zusman	(2012)	X									X				
Yang	(2004)													X	
Wichmann	(2004)														X

1: lung cancer; 2: pleural cancer; 3: skin cancer; 4: bladder cancer; 5: prostate cancer; 6: oropharyngeal cancer; 7: stomach cancer; 8: trachea cancer; 9: kidney cancer; 10: non-Hodgkin lymphoma; 11: multiple myeloma; 12: leukemia; 13: preterm birth; 14: pulmonary function.

and that in a 10-year period (1995-2004), the number of cases doubled the expected numbers for this particular disease.[26] Just as the reports by Christie (1991) and Järvholm (1997), they considered that leukemia development is linked to benzene exposure, more than to PAH exposure.

Contrary to the results reported by Barregard (2009), Axelsson et al. (2010) conducted a study in the Stenungsund region in the same country. Said study included cancer records from 1974 to 2005, specifically leukemia, lymphoma, liver cancer, and brain cancer. In their results they did not present significant differences between the total of observed cases and the number of expected cases, for any cancer type, consequently the author concludes that for this area cancer incidence was not affected by industrial emissions from refineries.[27]

Moreover, as a response to the public and scientific preoccupation of the possible risks involved in living near refineries, Wilkinson et al. (1999) conducted a study which included 11 refineries in Great Britain, where they evaluated the incidence of lympho-hematopoietic diseases linked to refinery pollutant exposure. The analysis was performed taking into account the distance between refineries and the place where the individuals included in the study lived, for this purpose they established 8 rings around the refineries' perimeters with a maximum distance of 7.5 Km. In their results, they observed a decline in the risk of Hodgkin lymphoma as the distance from the refineries increased.[28]

Zusman et al. also associated the risks of cancer linked to living in the proximity of an industrial area with the presence of oil refineries and oil and petrochemical storage facilities. Their results are very similar to Wilkinson's, because they showed that lung cancer and non-Hodgkin lymphoma incidence tended to decrease as the distance to storage facilities increased, especially among the elderly.[29]

Another important health effect on the population living near refineries is the rise in the incidence of premature births. Regarding this issue, in Taiwan they evaluated its incidence in infants born within 3 towns located 3 Km from oil refineries. The amount of considered births was 7,095 (cases) and 57,483 (controls), results showed an adjusted odds ratio of 1.14 (95% CI) for premature births when they compared refinery areas and control zones, these results provide evidence of the link between living in areas with atmospheric pollution caused by oil refineries and premature birth risk.[30]

Furthermore, in Argentina they evaluated the impact on respiratory health in children, under the hypothesis that children who live near refineries and petrochemical plants would have more serious health consequences, compared to those children who live in areas outside this source. In this study, they considered 181 children from 4 different areas (industrial, urban and 2 control sites). In order to evaluate their pulmonary function a spirometry was performed on every child as well as a survey. Results showed that children who lived in the industrial region showed a significant increment in adverse side effects in respiratory health, presenting a higher asthma prevalence ($p<0.001$), more asthma exacerbations ($p<0.001$), and more respiratory symptoms ($p<0.001$), as well as diminished respiratory function.[31]

Conclusions

Without a doubt, air pollution because of industrial emissions has become a matter of concern more and more due to its harmful effect on the health of the population. Different researches show that the industry's growth in urban areas is frequently connected to high levels of atmospheric pollutants, at the same time these levels are connected to the rise and exacerbation of different diseases.[32]

Nevertheless, there is no evidence of the health impact of all environmental pollutants. While PAHs are considered to be potentially carcinogenic and mutagenic, and thus we could consider them responsible for the health impact caused by exposure to refinery emissions, according to the reviewed literature we can conclude that PAHs are not the only ones participating in this process. In some cases, the effect is on bone marrow cells. Leukemia, non-Hodgkin lymphoma and multiple myeloma, are more connected to exposure to compounds such as benzene, while lung, airways, urinary tract and skin cancer, have been related more to PAH exposure.

Thus, we are not overlooking the fact that atmospheric pollution corresponds to a complex mixture of different toxic substances and from different sources that can hardly be identified.

Therefore, we suggest the development of environmental evaluations that allow us to identify organic compounds like PAH in different substrates, developed simultaneously with studies of the health impact in exposed populations in order to establish more direct connections with the health effects in humans and the emission source of these compounds.

Conflicts of interest

The authors have no conflicts of interest to declare.

Funding

No financial support was provided.

References

1. Kelly FJ, Fussell JC. Air pollution and airway disease. Clinical and Experimental Allergy 2011;41:1059-1071.
2. Prüss-Üstün A, Corvalán C. Cáncer de Ambientes saludables y prevención de enfermedades: hacia una estimación de la carga de morbilidad atribuible al medio ambiente, Organización Mundial de la Salud; 2006.
3. Consultado en enero de 2013. http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=122&tid=25
4. Vargas M. La contaminación ambiental como factor determinante de la salud. Rev Esp Salud Pública 2005;79:117-127.
5. Tomić Spirić V, Janković S, Jović Vraneš A, et al. The impact of air pollution on chronic respiratory diseases. Pol J Environ Stud 2012;21:481-490.
6. Amador-Muñoz O, Delgado-Rodríguez A, Villalobos-Pietrini R, et al. Partículas suspendidas, hidrocarburos aromáticos policíclicos y mutagenicidad en el suroeste de la ciudad de México. Rev Int Contam Ambient 2001;17:193-204.
7. Plisková M, Vondrácek J, Vojtesek B, et al. Deregulation of Cell Proliferation by Polycyclic Aromatic Hydrocarbons in Human Breast Carcinoma MCF-7 Cells Reflects Both Genotoxic and Nongenotoxic Events. Toxicological Sciences 2005;83:246-256.
8. Mastandrea C, Chichizola C, Ludueña B, et al. Hidrocarburos aromáticos policíclicos. Riesgos para la salud y marcadores biológicos. Acta Bioquím Clín Latinoam 2005;39:27-36.

9. Ravindra K, Sokhi R, Van Grieken R. Atmospheric polycyclic aromatic hydrocarbons: Source attribution, emission factors and regulation. Atmospheric Environment 2008;42:2895–2921.
10. Consultado en marzo de 2013. http://www.epa.gov/airquality/urbanair/
11. IARC, International Agency for Research on Cancer. Some Non-heterocyclic Polycyclic Aromatic Hydrocarbons and Some Related Exposure. Monographs on the Evaluation of Carcinogenic Risks to Humans, Word Health Organization; 2010. p. 92.
12. Olajire A, Brack W. Polycyclic aromatic hydrocarbons in Niger Delta soil: contamination sources and profiles. Int J Environ Sci Tech 2005;2:343-352.
13. Díaz-González G, Vázquez-Botello A, Ponce-Vélez G. Contaminación por hidrocarburos aromáticos y policíclicos (HAP´S) disueltos en la laguna Mecoacán, Tabasco, México. Hidrobiológica 1994;4:21-27.
14. Rao B, Ansari M, Pipalatkar P, et al. Monitoring and assessment of particulate matter and poly aromatic hydrocarbons (PAHs) around a petroleum refinery. Bull Environ Contam Toxicol 2007;79:197-201
15. Tiwari J, Chaturvedi P, Ansari N, et al. Assessment of Polycyclic Aromatic Hydrocarbons (PAH) and Heavy Metals in the Vicinity of an Oil Refinery in India. Soil and Sediment Contamination 2011;20:315-328.
16. Yassaa N, Cecinato A. Composition of torched crude oil organic particulate emitted by refinery and its similarity to atmospheric aerosol in the surrounding area. Chemosphere 2005;60:1160-1166.
17. Cazier F, Dewaele D, Delbende A, et al. Sampling analysis and characterization of particles in the atmosphere of rural, urban and industrial areas. Procedia Environmental Sciences 2011;4:218-227.
18. Rehwagen M, Müller A, Massolo L, et al. Polycyclic aromatic hydrocarbons associated with particles in ambient air from urban and industrial areas. Science of the Total Environment 2005;348:199-210.
19. Di Filippo P, Riccardi C, Pomata D, et al. Seasonal Abundance of Particle-Phase Organic Pollutants in an Urban/Industrial Atmosphere. Water Air Soil Pollut 2010;211:231-250.
20. Bozlaker A, Muezzinoglu A, Odabasi M. Atmospheric concentrations, dry deposition and air-soil exchange of polycyclic aromatic hydrocarbons (PAHs) in an industrial region in Turkey. Journal of Hazardous Materials 2008;153:1093-1102.
21. Christie D, Robinson, Gordon I, et al. A prospective study in the Australian petroleum industry. I Mortality and II Incidence of cancer. British Journal of Industrial Medicine 1991;48:507-514.
22. Järvholm B, Mellblom B, Norrman R, et al. Cancer incidence of workers in the Swedish petroleum industry. Occupational and Environmental Medicine 1997;54:686-691.
23. Wong O, Raabe G. A Critical Review of Cancer Epidemiology in the Petroleum Industry, with a Meta-analysis of a Combined Database of More Than 350,000 Workers. Regulatory Toxicology and Pharmacology 2000;32:78-98.
24. Kaldor J, Harris J, Glazer E, et al. Statistical association between cancer incidence and major-cause mortality, and estimated residential exposure to air emissions from petroleum and chemical plants. Environmental Health Perspectives 1984;54:319-332.
25. Yang C, Cheng M, Chiu J, et al. Female lung cancer risk and petrochemical air pollution in Taiwan. Arch Environ Health 1999;54:180-185.
26. Barregard L, Holmberg E, Sallsten G. Leukaemia incidence in people living close to an oil refinery. Environmental Research 2009;109:985-990.
27. Axelsson G, Barregard L, Holmber E, et al. Cancer incidence in a petrochemical industry area in Sweden. Science of the Total Environment 2010;408:4482–4487.
28. Wilkinson P, Thakrar B, Walls P. Lymphohaematopoietic malignancy around all industrial complexes that include major oil refineries in Great Britain. Occup Environ Med 1999;56:577-580.
29. Zusman M, Dubnov J, Barchana M, et al. Residential proximity to petroleum storage tanks and associated cancer risks: Double Kernel Density approach vs. zonal estimates. Science of the Total Environment 2012;441:265-276.
30. Yang C, Chang C, Chuang H, et al. Increased risk of preterm delivery among people living near the three oil refineries in Taiwan. Environment International 2004;30:337–342.
31. Wichmann F, Müller A, Busi L, et al. Increased asthma and respiratory symptoms in children exposed to petrochemical pollution. J Allergy Clin Immunol 2009;123:632-638.
32. Srogi K. Monitoring of environmental exposure to polycyclic aromatic hydrocarbons: a review. Environmental Chemistry Letters 2007;4:169-195.