Environ Geochem Health (2025) 47:321
https://doi.org/10.1007/s10653-025-02619-1

ORIGINAL PAPER

Polycyclic aromatic hydrocarbons skin exposure among coke workers and skin cancer correlation: local data bank and case study

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Received: 16 March 2025 / Accepted: 19 June 2025 / Published online: 17 July 2025

Abstract Polycyclic aromatic hydrocarbons (PAHs) are a group of persistent environmental pollutants, recognized as carcinogens to the human body and associated with increased cancer risk, particularly in occupationally exposed workers. This study aims to collect a database and evaluate the dermal exposure to PAHs among workers at an Italian coke plant and investigate the possible correlation with the development of skin cancer. Epidermal pads were applied to the skin of 166 coke plant workers during a work shift and quantified the deposition of different PAHs using gas chromatography coupled with mass spectrometry (GC–MS). Forehead and forearms were the anatomical regions with the highest PAHs exposure ($p < 0.001$). Fossil/furnace departments workers had the highest cutaneous exposure to total PAHs concentration ($p < 0.001$). No significant correlation was found with skin cancers. However, no significant correlation was observed between skin exposure to PAHs and the development of skin cancer among workers in the short term. Further control studies are needed to assess in the long term the risk of developing skin cancers among coke workers exposed to PAHs. These results suggest that coke factory workers are at risk of significant skin exposure to PAHs. Further long-term studies are needed to fully evaluate the potential health impacts of this occupational exposure.

Keywords Dermatology · Cutaneous absorption · Melanoma · Non-melanoma skin cancer · Polycyclic aromatic hydrocarbons

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Introduction

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds formed by two or more benzene rings, which ubiquitously pollute the environment and workplaces. Forest fires, natural oils, and volcanic eruptions are natural sources of PAHs. Still, PAHs are also produced from petroleum derivatives, waste combustion, heating systems, and car exhaust. They are known due to their potential carcinogenic properties, as exposure to PAHs is associated with an increased risk of cancer in workers who come into contact with these molecules (Abdel-Shafy et al., 2016). The International Agency for Research on Cancer (IARC) rates 16 PAHs as proven, probable or possible human carcinogens (Hussein & Mona 2016, IARC, 2014). Even at low concentrations, PAHs penetrate the skin by absorption and/or diffusion and are locally metabolised and distributed to other tissues/organs by the bloodstream. Lighter PAHs have higher dermal permeability and absorption rates than heavier compounds. Topical PAHs activate the aryl hydrocarbon receptor and promote reactive products' enzymatic formation, leading to protein and/or DNA adducts (Sousa et al., 2022 Oct 4). Within organisms, PAHs undergo an activation process, mediated by phase I enzymes such as cytochrome P450 monooxygenases (CYP) and phase II enzymes, and are transformed into toxic active compounds such as epoxides (La Maestra et al., 2025a, La Maestra et al., 2025b). These active metabolites induce DNA mutations with adduct formation, altering gene expression profiles with possible induction of carcinogenesis (Moorthy et al., 2015). In particular PAHs exposure is associated with tumours in different districts such as, lung, bladder and skin cancer (Abdel-Shafy et al., 2016; Moorthy et al., 2015; Hwang et al., 2021; Boffetta et al., 1997, ASTDR; Atlanta, GA, USA: 2015). These types of cancers have been found more frequently in exposed workers, namely in coke workers, asphalters, and firefighters (Ballarin et al., 2014; Gao et al., 2018; Stec et al., 2018). Exposure routes to PAHs occur by inhalation, ingestion, and skin absorption (Hwang et al., 2021; IARC, Lyon France 2010. In particular, dermal absorption was demonstrated to be the main route— notably even superior to the inhalation route—of uptake of PAHs among coke oven workers, as in these work contexts, epidermal deposition of PAHs may be continuous and prolonged. (Van Rooji et al., 1993a).

Although it is difficult to assess an increased risk in the development of skin cancer in relation to occupational exposures, based on mortality studies alone at least one epidemiological study with long-term follow-up has found an increased risk of cutaneous melanoma and nonmelanoma skin cancer (NMSC) in firefighters, who are workers known to be exposed to PAHs (Pukkala et al., 2014). Moreover, a literature review found significant correlations between the exposure to whole petroleum hydrocarbons, including PAHs, among petrochemical refinery workers, and the occurrence of malignant melanoma, also on non-sun exposed skin (Van Rooji et al., 1993b). Endogenous risk factors may also influence the risk of developing skin cancer. A fair skin, namely a phototype I or II, may increase the risk of sunburns and chronic sun damage, therefore the risk of skin cancer. Moreover, a family history of skin cancer as well as a history of sunburns in childhood and adolescence may also predispose to develop skin cancer. (Gordon, 2013 Aug).

This study aimed to evaluate different levels of epidermal exposure to PAHs. in an Italian coke factory to determine the workers with the highest exposure based on their jobs within the factory and to provide a database for future studies on the occurrence of skin cancer in exposure work settings.

Materials and methods

Study population

We conducted an observational study on coke workers employed at the Italiana Coke Company of Cairo Montenotte, Liguria, Italy. All workers underwent clinical dermatological and dermoscopic examination. Each subjects phototype, personal and family history of skin tumours, sunburns in childhood, sun exposure during life, smoking, weight (kg), height (cm), and Body Mass Index (BMI) were recorded. Strict QA/QC procedures are essential when collecting and storing skin PADs samples for PAH analysis to ensure data integrity. For the study, PADs were applied to predefined skin areas using consistent placement and exposure duration for all subjects, to minimise variability. Prior to extraction, all PADs have been stored in containers that are free from contaminants to avoid background interference. Samples had been clearly labelled with unique identifiers including the time of collection, the anatomical site, and the duration of exposure (the standard eight-hour work shift). To preserve chemical stability, the collected swabs were stored at low temperatures: ideally at 4 °C for short-term handling, and at -20 °C or below for long-term storage. All steps, from sample collection to storage and transport, were carefully documented to maintain traceability and support the chain of custody. At the same time blank samples have been prepared and extracted to ensure the correctness of the analysis and to avoid the presence of environmental contaminants.

The Personal Protection Equipment (PPEs) used by workers in direct contact with any source of PAHs were gloves, a mask, and glasses, changed at every single work shift. The workers in the administration department only wore PPE when needed. Patches were applied to never be in direct contact with any PPE.

We divided the workers into seven groups, according to their tasks: fossil/furnace department workers (storing of fossil coals and preparing mixtures of fossil coals / transformation of the fossil coal mixture into coke employing pyrolysis); mechanical maintenance department workers (transversal activities in the various areas of the plant); gas cycle/coke department workers (handling coke oven gases produced by the pyrolysis of fossil coal/ screening, grinding coal and loading trucks/rail wagons for coal shipment); electricians; cogeneration department workers (producing electricity and steam using combustion engines powered by coke oven gas and recovery steam generators); laboratory staff [analytical determinations on raw materials (coals), products (coke), and intermediates (coke oven gas, wastewater); technicians/administrative staff (office work). All the morphometric and epidemiological data of the worker are summarized in (Table 1).

Table 1 Demographic and clinical characteristics of the study group

Phototype	I	2 (1.21%)
	II	49 (29.51%)
	III	95 (57.24%)
	IV	20 (12.04%)
	V	0 (0%)
	VI	0 (0%)
Personal history of skin cancers	Yes	0 (0%)
	No	166 (100%)
Family history of skin cancers	Yes	0%
	No	166 (100%)
Sunburns in childhood	Yes	89 (53.6%)
	No	77 (46.4%)
Active smoker	Yes	41 (24.7%)
	No	125 (75.3%)
Height cm (mean ± SD)	176.46 ± 6.46	
Weight kg (mean ± SD)	81.61 ± 12.72	
BMI kg/m^2 (mean ± SD)	26.2 ± 3.6	

Reported data include morphometric variables (age, sex, height, weight, BMI), family history of skin cancer, skin phototype (classified according to the Fitzpatrick scale), and smoking status

Analysis of polycyclic aromatic hydrocarbons (PAHs)

The concentration of PAHs was evaluated by using alpha cellulose pads applied on the skin with a thin line of medical plaster perimeyrically, and kept during the work shift (Cagimbra SAS, Cecina Livorno, Italy). To evaluate the skin exposure in different sites the pads were applied in seven different skin areas: forehead, back, abdomen, dominant arm, dominant forearm, thigh and calf. The pad applied to the forehead was the only one that detected direct PAHs deposition on the skin, in the remaining body sites the pads were covered by clothing. The diameter of the single pad used was 3.24 cm, with a surface area of 10.18cm^2. The total surface area of the seven applied pads was 71.26cm^2. The pads were applied at the beginning of the work shift and removed at the end of the shift, so they remained on the skin for approximately eight hours. No coal or coke powder was observed on the pads, as it proves how PAHs can bypass physical barriers and come in contact with the skin directly.

Pads were removed and washed three times with 3 mL of hexane solution. Hexane solution was pooled, and the obtained volume was dried under nitrogen. No significant loss of analytes was observed during drying. The dried samples were resuspended in 100 µL of hexane 5 µL were injected in a HP5890 series II gas chromatograph coupled to a HP5972 mass spectrometer equipped with an electron impact ionization source (Agilent). The GC separation was performed on a DB5MS capillary column (Phenomenex, 0.25 mm × 30 m, 0.25 µm film thickness); the helium gas flow was 1 mL/min. The oven temperature gradient was as follows: initial temperature of 80 °C, isothermal at 80 °C for 3 min, 80 °C to 240 °C (rate, 30 °C/min), 240 °C to 300 °C (50 °C/min) and isothermal at 300 °C for 15 min. as previously described (Pietrogrande M.C. et al., 2014) albeit with slight modifications to better suit this work. The QA/QC procedures used in this work followed the guidelines from Clement and Koester (Clement & Koester, 1995). Mass spectrometry parameters were carefully optimized to maximize sensitivity while avoiding saturation. Furthermore, injection volumes of 1, 2, and 5 µL were evaluated in preliminary tests, with 5 µL selected for providing the best signal-to-noise ratio without compromising chromatographic performance. Calibration standards at concentrations of 5, 10, 50, 100, and 200 ng/mL were prepared by serial dilution from a stock solution in hexane at 2 µg/µL.

After that PAH standards have been extracted and analysed, we had a recovery of both analytes and standards after drying under a cold nitrogen stream consistently ranged between 94.5% and 97%. The mass spectrometry (MS) analysis was performed in Selected Ion Monitoring (SIM) mode using specific signals for each compound of interest. Even if, the same m/z was chosen for different molecules, it was possible to unambiguously refer to specific compounds thanks to the different retention times (Table 3) By operating the GC/MS in Selected Ion Monitoring (SIM) mode, we achieved a substantial increase in analytical sensitivity and selectivity, allowing for the reliable detection and quantification of low-level polycyclic aromatic hydrocarbons (PAHs). This approach enabled us to minimize background noise and enhance signal-to-noise ratios for target ions, leading to limits of quantification (LOQs) ranging from 0.05 to 5 ng/mL, depending on the specific analyte. These values are consistent with those commonly reported in the literature for SIM-based PAH analyses. PAH separation was set up and their quantification was performed using a calibration curve obtained by injecting a mix of 13 PAH standard (SIGMA-ALDRICH, EPA 525 PAH Mix A) chosen after an accurate evaluation of the compounds found in pads previously picked at random. All the eluents and were purchased from Merck Life Science S.r.l. (Via Monte Rosa 93, Milano, 20,149, Italy.

Statistical methods

Mean with standard deviation and median with interquartile range (IQR) were reported for concentrations. We performed a statistical analysis comparing the total concentration of PAHs and the concentration of four selected PAHs (pyrene, chrysene, benzo[a]pyrene and dibenz[a,h]anthracene), belonging to different categories of human carcinogenicity according to IARC (IARC, Lyon France 2010). The non-parametric Kruskal–Wallis test was used to test global differences on concentrations among the different working unit, among the body parts and according to the smoking status. The Mann–Whitney test was used for each comparison between two working units or between two body parts. The p-value was adjusted for multiple comparisons using the false-discovery rate approach. Spearman's rho was calculated to assess correlation between exposure, BMI and each PAH concentration. A multivariable linear regression model with each concentration as dependent variable was performed. Working unit, BMI and smoke status were considered as independent variables when significantly associated to concentration at univariable analyses. Stata (v.16; StataCorp) was used for the computation. A p-value < 0.05 was considered statistically significant.

The Italian coke worker trade union approved this study. All workers gave written informed consent. The study was conducted in respect of the Declaration of Helsinki. (Fig. 1).

Results

We enrolled 166 workers (165 males and 1 female; average age 49 years ± 5), with an average period of employment of 16 years. To summarize, fifty-seven percent of workers had a phototype 3, 29.5% of workers had a phototype 2, 12% of workers have a phototype 4 and 1.2% subject has a phototype 1. Eighty-nine (53.6%) workers reported a history of sunburns during childhood or adolescence. None of the workers reported a personal history of skin malignancy. Clinically, none of the workers presented skin lesions referable to melanoma or nonmelanoma skin cancer (NMSC). Only one worker had actinic keratoses. The distribution of smoking among the workers is summarized in (Table 2).

The PAHs searched from the pads applied on the skin were: acenaphthylene, fluorene, phenanthrene, anthracene, pyrene, chrysene, benz[a]anthracene, benzo[a]pyrene, benzo[k]fluoranthene, benzo[b]fluoranthene, indeno[1,2,3-cd] pyrene, benzo[ghi]perylene, dibenz[a,h]anthracene (Table 3).

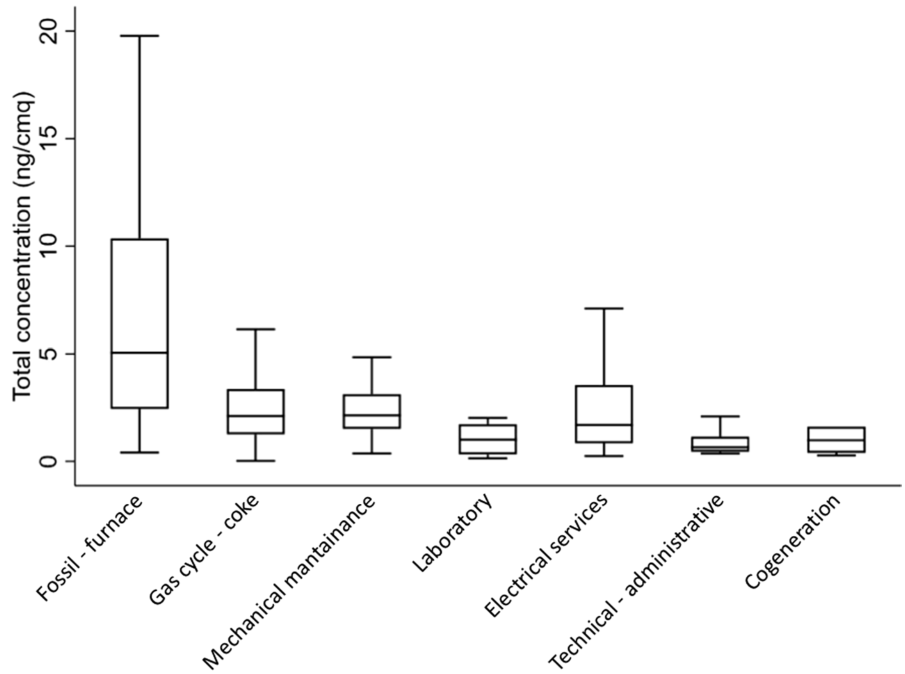

Fig. 1 Median and total dstribution concentrations of PAHs, extracted from pads and determined in GC/MS, across the various departments of a coke factory

Table 2 Distribution of smoking status and average number of cigarettes smoked per day among workers across the different production sectors of the factory

	Smoking			
Work department	NO	< 10 cigarettes/day	> 10 cigarettes/day	Total
Fossil-furnaces	9	25	37	71
%	12.68	35.21	52.11	100
Gas	5	21	20	46
%	10.87	45.65	43.48	100
Maintenance	6	1	2	9
%	66.67	11.11	2.22	100
Laboratory	0	7	1	8
%	0.00	87.50	12.50	100
Electrical services	3	3	7	13
%	23.08	23.08	53.85	100
Cogeneration	3	2	2	7
%	42.86	28.57	28.57	100
Total	26	59	69	154
%	16.88	38.31	44.81	100

The table highlights the prevalence of current smokers and the mean daily cigarette consumption within each sector. Data are presented for all operational departments, with the exception of the administrative staff, who were excluded from this analysis

The anatomical regions with the highest exposure to PAHs were the forehead and forearm ($p < 0.001$) (Table 4).

Workers of the fossil/furnace departments had the highest cutaneous exposure vs. all other departments both in terms of overall PAHs concentration (5.1 ng/cm^2) and of individual PAHs (pyrene 0.57 ng/cm^2, chrysene 0.18 ng/cm^2 and benzo[a]pyrene 0.08 ng/cm^2) ($p < 0.001$) (Fig. 1). Decreasingly lower concentrations of PAHs were found in gas cycle/coke department workers, mechanical maintenance department worker, electricians, laboratory staff, cogeneration department workers and technicians/administrative staff (Fig. 1, Table 3). Gas cycle/coke department and workers of the mechanical maintenance department had similar cutaneous concentrations of PAHs, except for benzo[a]pyrene, which was not detected in mechanical maintenance department workers. Laboratory staff and workers of the cogeneration department had similar PAHs deposition. Technicians and administrative staff were exposed to the lowest concentration of PAHs and only to a (total concentration of 1.0 ng/ cm^2, pyrene 0.09 ng/ cm^2 and chrysene 0.01 ng/ cm^2 and chrysene) ($p < 0.001$).

In pairwise comparisons, significant differences in total concentration were observed in the gas cycle/coke department workers vs cogeneration department

Table 3 List of the polycyclic aromatic hydrocarbons (PAHs) included in the analysis, along with their corresponding retention times (RT) and monitored ions (m/z)

Compound	Retention range (set for SIM)	Retention time	Ion monitored
Acenaphthylene	7.5–9.0	8.0	152.1
Fluorene	7.5–9.0	8.6	166.1
Phenanthrene	9.0–10.5	9.5	178.1
Anthracene	9.0–10.5	9.6	178.1
Pyrene	10.5–11.8	10.9	202.1
Chrysene	11.8–13.8	12.3	228.1
Benz[a]anthracene	11.8–13.8	12.4	228.1
Benzo[a]pyrene	13.8–17.0	14.1	252.1
Benzo[k]fluoranthene	13.8–17.0	14.2	252.1
Benzo[b]fluoranthene	13.8–17.0	14.9	252.1
Indeno[1,2,3-cd]pyrene	17.0–25.0	18.2	276.1
Benzo[ghi]perylene	17.0–25.0	18.4	276.1
Dibenz[a,h]anthracene	17.0–25.0	19.3	278.1

The retention time refers to the time at which each compound eluted during chromatographic separation, while the monitored ion represents the specific mass-to-charge ratio used for detection in the mass spectrometer, selected to ensure compound identification and quantification with optimal sensitivity and specificity

Table 4 Average concentrations of polycyclic aromatic hydrocarbons (PAHs) detected on different anatomical regions sampled using pads

	Total concentration (ng/cm^2)	p-value
Front	1.27 (2.41) 0.34 (0.15–1.27)	< 0.001
Back	0.45 (0.93) 0.18 (0.09–0.39)	
Abdomen	0.48 (1.07) 0.18 (0.08–0.38)	
Dominant arm	1.45 (9.06) 0.30 (0.12–0.74)	
Forearm	0.96 (1.95) 0.41 (0.16–0.81)	
Thigh	0.93 (2.51) 0.23 (0.11–0.60)	
Calf	0.82 (2.41) 0.22 (0.08–0.54)	

The data highlight the distribution of PAH exposure across the investigated body areas. The forehead and forearm exhibited the highest PAH levels, with the exposure difference being statistically significant based on median concentration values

workers and also in laboratories staff vs gas cycle/coke department workers. In addition, there was a significant difference in total concentration in the technical staff vs the gas cycle /coke, maintenance and electrical department workers (Table 4).

Forty-one (24.7%) subjects were active smokers. In univariable analyses smoking status seemed to have the greatest impact on benz[a]pyrene concentration ($p = 0.023$) with a higher concentration in smokers than in non-smokers workers. For the other PAHs' concentrations, despite higher mean and median values in smokers, the variability was so large to undermine any significant difference; no significant univariable correlation was observed for chrysene ($r = -0.08$; $p = 0.33$) or dibenz[a,h]anthracene ($r = -0.036$; $p = 0.64$) (Table 4).

The average BMI was 26.2 kg/m2 ± 3.6. The correlation with BMI appeared low despite being significant for total concentration ($r = -0.15$; $p = 0.048$) and for benzo[a]pyrene ($r = -0.16$; $p = 0.042$), with lower concentration values for high BMI values.

As a final analysis, multivariable linear regression was used to assess the association between work department and PAHs skin concentration, adjusting for potential confounders such as BMI and smoking status. (Tables 5 and 6).

For total PAH concentration, significant differences among work departments were confirmed even after adjustment ($p < 0.001$), with BMI also being independently associated ($p = 0.024$), while smoking status showed no significant effect ($p = 0.97$). The coefficient of determination (R^2)

Table 5 This table reports the concentrations of [substance/parameter] expressed as mean (standard deviation) and median (25th to 75th percentile)

	Total Conc (ng/cm^2)	Pyrene (ng/cm^2)	Benz[a]pyrene (ng/cm^2)	Chrysene (ng/cm^2)	Dibenz[a,h]anthracene (ng/cm^2)
N = 166	6.3 (14.3) 2.44 (1.26–5.69)	0.76 (1.67) 0.24 (0.09–0.63)	0.11 (0.23) 0.02 (0–0.08)	0.23 (0.45) 0.09 (0.03–0.21)	0.04 (0.11) 0 (0–0.02)
Fossil-Furnace (n = 72)	11.4 (20.6) 5.1 (2.4–10.4)*	1.41 (2.37) 0.57 (0.20–1.45)*	0.21 (0.31) 0.08 (0.01–0.26)*	0.44 (0.63) 0.18 (0.08–0.45)^°	0.07 (0.16) 0 (0–0.06)*
Mechanical (n = 9)	3.3 (3.9) 2.1 (1.5–3.1)	0.25 (0.27) 0.18 (0.13–0.22)	0.01 (0.03) 0 (0–0)	0.07 (0.12) 0.02 (0–0.06)	%1.%2 (0.01) 0 (0–0)
Gas (n = 47)	2.9 (2.6) 2.1 (1.3–3.4)	0.34 (0.43) 0.19 (0.07–0.36)	0.03 (0.05) 0.01 (0–0.06)	0.10 (0.10) 0.07 (0.02–0.14)	%1.%2 (0.02) 0 (0–0.01)
electrical services (n = 13)	2.6 (2.2) 1.7 (0.8–3.6)	0.27 (0.24) 0.16 (0.09–0.42)	%1.%2 (0.02) 0(0–0.01)	0.08(0.07) 0.06 (0.02–0.13)	0.00(0.01) 0 (0–0)
Cogeneration (n = 7)	2.1 (3.3) 1.0 (0.4–1.6)^	0.11 (0.05) 0.09 (0.07–0.12)	%1.%2 (0.03) 0(0–0.02)	0.03(0.04) 0.01 (0.01–0.02)^°	%1.%2 (0.01) 0 (0–0)
Laboratory (n = 9)	1.4 (1.5) 1.0 (0.3–1.7)^	0.18 (0.20) 0.09 (0.05–0.28)	%1.%2 (0.03) %1.%2 0 (0–0)	0.05 (0.06) 0.03 (0.02–0.05)	%1.%2 (0.02) %1.%2 0 (0–0)
Administrative (n = 9)	0.9 (0.6) 0.6 (0.4–1.2)^§°	0.10 (0.09) 0.09 (0.03–0.16)	0.05 (0.13) 0 (0–0)	%1.%2 (0.10) %1.%2 (0–0.10)	0.06 (0.18) 0 (0–0.002)

Statistical significance is indicated by symbols: * denotes a significant difference compared to all other departments; ^ denotes a significant difference compared to the Gas Cycle/Coke department; § denotes a significant difference compared to the Maintenance department; and ° denotes a significant difference compared to Electrical Services. These markers highlight the differences in exposure levels across the various departments examined

Table 6 The table shows that smoking status had the greatest impact on Benzo(a)pyrene concentrations ($p = 0.023$), with higher levels observed in smokers compared to non-smokers

Smokers	Total conc. (ng/cm^2) Mean (SD) / Median (IQR)	Pyrene (ng/cm^2) Mean (SD) / Median (IQR)	Benzo(a)yirene (ng/cm^2) Mean (SD) / Median (IQR)	Crysene (ng/cm^2) Mean (SD) / Median (IQR)	Dibenzo anthracene (ng/cm^2) Mean (SD) / Median (IQR)
No (n = 26)	3.78 (3.64) 2.29 (1.67–5.04)	0.33 (0.49) 0.17 (0.09–0.42)	0.08 (0.20) 0 (0–0.02)	0.14 (0.26) 0.06 (0.01–0.13)	0.04 (0.12) 0 (0–0)
< 10 cigarettes/day (n = 59)	5.55 (12.23) 2.45 (1.42–5.15)	0.78 (1.43) 0.34 (0.14–0.78)	0.09 (0.20) 0.03 (0–0.07)	0.20 (0.33) 0.09 (0.04–0.20)	%1.%2 (0.10) 0(0–0.02)
> 10 cigarettes/day (n = 69)	8.76 (18.81) 2.95 (1.20–7.29)	1.01 (2.18) 0.30 (0.09–0.70)	0.14 (0.26) 0.03 (0–0.16)	0.33 (0.60) 0.13 (0.02–0.25)	0.04(0.12) 0 (0–0.01)

Results are presented as mean (standard deviation) and median (interquartile range)

increased from 0.27 (model with department only) to 0.30 when BMI was included.

A similar pattern was observed for pyrene: work department remained significantly associated ($p < 0.001$) after adjusting for BMI ($p = 0.018$), with smoking status again not significant ($p = 0.18$). R^2 increased from 0.21 to 0.23 with the addition of BMI.

For benzo[a]pyrene, both work department ($p < 0.001$) and BMI ($p = 0.022$) were significantly associated, while smoking status was not ($p = 0.62$); the model had an R^2 of 0.26.

In contrast, neither BMI nor smoking status were significantly associated with chrysene ($p = 0.15$ and $p = 0.37$, respectively) or with dibenz[a,h]anthracene ($p = 0.49$ and $p = 0.86$, respectively).

Discussion

Our study confirms the skin exposure to carcinogenic PAHs in coke workers. Our results are in line with previous studies that quantified PAHs via skin pads applied during work shifts in asphalt-pavers to pyrene and benz[a]pyrene on average 0.53 ng/cm^2 and 0.063 ng/cm^2 respectively (Fustinoni et al., 2010). On the other hand, we detected lower median concentration of pyrene (0.24 ng/cm^2) as compared to previous studies (6.4 ng/cm^2) (Van Rooji et al., 1993b). Moreover, previous studies on coke workers utilize pyrene as the main indicator of PAHs exposure, but we also consider benzo[a]pyrene, which is one of the most harmful among PAHs as it is classified as a certain carcinogen.

As expected, the workers of the fossil/furnace departments had the highest skin exposure to PAHs, both in terms of the total components and the individual PAHs examined. While, technicians/administrative staff, had significantly a lower PAH/skin concentration, and they could almost be considered an internal control group since they work on the plant but do not perform tasks directly involving fossil coal or coke processing. The personnel of the gas cycle/coke department and the personnel employed in the electrical and mechanical maintenance departments follow the furnace/fossil department workers in terms of skin exposure, but the median concentration values were less than half. Analysis of statistical data suggest that the fossil/furnace workers have a significant difference, or at least a trend of difference at the limits of significance compared to gas cycle/coke works and a significant difference compared to maintenance workers and technicians/administrative staff.

The most exposed skin site was the dominant forearm, followed by the forehead and arm. It should be noted that the dominant forearm, even if the pad was covered by clothing, was the one most in contact with the product. On the forehead, on the other hand, the pad had no interface, and this could justify the higher concentration of PAHs compared to the other anatomical sites at a distance, such as the lower limbs and the back.

Coke workers are notoriously exposed to PAHs and have been shown, in literature, to have a higher incidence of skin neoplasm (IARC, Lyon France 2010; Pukkala et al., 2014). Skin exposure is the main way of exposure to PAHs (IARC, Lyon France 2010). Yet, many factors may influence the occurrence of skin cancers, including genetic predisposition, phototype and sun exposure. Studies conducted from a dermatological point of view, that assess the in-depth dermatological anamnesis of family and personal history of skin tumors, sun exposure and sunburns of workers and include a full clinical and dermoscopic assessment are scanty.

Although this study found no significant correlation between skin exposure to PAHs and skin cancers over a short or very short period, a confounding factor could be detected in cigarette smoking. A higher total and individual concentration of PAHs on swabs was found in the smoking group than in nonsmokers. In particular, the concentration of benz[a]pyrene was found to be statistically significant. This finding should be considered in future studies and also demonstrates that the accumulation of PAHs from diverse sources in both exposed workers and the general population should not be neglected.

Conclusions

There is little work in the literature related to coke work associated with dermal exposure to PAHs. A large and significant number of exposed subjects were examined in this work,

reaching more statistically significant values. Workers who work closely with coal/coke processing have shown elevated skin deposition of PAHs, but this does not appear to correlate with increased incidence of skin cancer in the short and very short term. However, further prospective studies are needed to evaluate the long-term effects of skin deposition of PAHs in coke-exposed workers. As a primary preventive measure, the use of personal protective equipment for coke workers should be encouraged.

Author Contributions L.G, G.G, A.S, A.S and M.B wrote the main manuscript, A.S worked on statistical analysis, A.S prepared the figures, A.S, G.D and M.B worked on samples preparation and analysis all authours contributed with data collection and literature review, all authors reviewed and approved the manuscript.

Funding This work received no funding.

Data availability Data will be provided after kind and motivated request.

Declarations

Conflict of interest The authors declare no competing interests.

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