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RESEARCH ARTICLE (ORIGINAL)

1-Hydroxypyrene in the urine of health professionals exposed to surgical smoke: Correlation with signs and symptoms

1-Hidroxipireno na urina de trabalhadores expostos ao fumo cirúrgico: Relação com os sinais e sintomas

1-Hidroxipireno en la orina de trabajadores expuestos al humo quirúrgico: relación con signos y síntomas

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Abstract

Background: Surgical smoke includes bioaerosols and chemical compounds, such as polycyclic aromatic hydrocarbons, which can cause occupational diseases and work-related cancer.
Objective: To correlate the presence of 1-hydroxypyrene in the urine of health professionals with signs and symptoms associated with occupational exposure to surgical smoke and to determine the relationship between 1-hydroxypyrene levels in urine at the end of a shift and the use of personal protective equipment.
Methodology: A cross-sectional field study was conducted, collecting urine samples to determine the concentration of the metabolite 1-hydroxypyrene.
Results: Exposure to surgical smoke increased the risk of signs and symptoms by 1.56 times (p = 0.000). Irritation of other mucous membranes contributed to a 1.20 increase in the risk of other signs and symptoms associated with surgical smoke exposure (p = 0.013).
Conclusion: The results show that the higher the levels of 1-hydroxypyrene in urine, the greater the likelihood of developing signs and symptoms. The use of personal protective eyewear was also considered to be a protective factor, reducing the risk of developing signs and symptoms.

Keywords: occupational health; polycyclic aromatic hydrocarbons; smoke; electrocoagulation

Resumo

Enquadramento: O fumo cirúrgico contém bioaerossóis e compostos químicos como Hidrocarbonetos Policíclicos Aromáticos, que podem causar doenças ocupacionais e até cancro.
Objetivo: Correlacionar a presença do metabólito 1-Hidroxipireno na urina dos trabalhadores com os sinais e sintomas relacionados à exposição ocupacional ao fumo cirúrgico e determinar associação entre os valores de 1-Hidroxipireno na urina ao final do turno com o uso de equipamento de proteção individual.
Metodologia: Estudo transversal de campo, coletados amostras de urina para determinar a concentração do metabólito 1-Hidroxipireno.
Resultados: A exposição ao fumo cirúrgico aumenta 1,56 vezes o risco de apresentar sinais e sintomas (p = 0,000). A irritação de outras mucosas colaborou com 1,20 vezes o risco de apresentar outros sinais e sintomas atrelados a exposição ao fumo cirúrgico (p = 0,013).
Conclusão: Quanto maior os níveis de 1-hidroxipireno na urina maior a probabilidade de desenvolver sinais e sintomas e o uso dos óculos de proteção apresentou-se como fator protetor reduzindo o risco de apresentar sinais e sintomas.

Palavras-chave: saúde ocupacional; hidrocarbonetos policíclicos aromáticos; fumaça; eletrocoagulação

Resumen

Marco contextual: El humo quirúrgico contiene bioaerosoles y compuestos químicos como los hidrocarburos aromáticos policíclicos, que pueden causar enfermedades profesionales e incluso cáncer.
Objetivo: Correlacionar la presencia del metabolito 1-Hidroxipireno en la orina de los trabajadores con signos y síntomas relacionados con la exposición laboral al humo quirúrgico y determinar una asociación entre los valores de 1-Hidroxipireno en orina al final del turno y el uso de equipos de protección individual.
Metodología: Estudio transversal de campo, muestras de orina recogidas para determinar la concentración del metabolito 1-Hidroxipireno.
Resultados: La exposición al humo quirúrgico aumenta 1,56 veces el riesgo de presentar signos y síntomas (p = 0,000). La irritación de otras mucosas contribuyó 1,20 veces al riesgo de presentar otros signos y síntomas relacionados con la exposición al humo quirúrgico (p = 0,013).
Conclusión: Cuanto más altos eran los niveles de 1-Hidroxipireno en la orina, mayor era la probabilidad de desarrollar signos y síntomas, y el uso de gafas de protección demostró ser un factor protector, pues reduce el riesgo de presentar signos y síntomas.

Palabras clave: salud laboral; hidrocarburos aromáticos policíclicos; humo; electrocoagulación

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Introduction

Surgical smoke is produced during surgical procedures using electric scalpels. This smoke contains bioaerosols, with viable or non-viable cells, and chemical compounds, such as polycyclic aromatic hydrocarbons (PAHs), that can cause occupational diseases and even work-related cancer in the health professionals exposed to them (Zhang et al., 2021; Zhou et al., 2023).

When absorbed by the human body, PAHs can cause the following signs and symptoms: dizziness, headache, nausea, vomiting, burning sensation in the throat, foreign body sensation in the throat, nasal congestion, sore throat, and watery eyes. PAHs are also considered to be mutagenic and carcinogenic and promote the development of cardiovascular and respiratory diseases (Caus et al., 2023; Zhang et al., 2021).

Despite the potential health risks, research on occupational exposure to PAHs is still developing and further investigation (Mallah et al., 2022) is needed to define ways to protect exposed professionals and prevent illness. Also, the eighth goal of the United Nations (UN) Sustainable Development Goals (SDGs) for 2030 recommends the promotion of economic growth and decent work to achieve safe and secure working environments that do not harm professionals' health (UN Brazil, 2015). Therefore, it is important to study this issue to find ways to protect exposed professionals and prevent illness.

Our study aimed to correlate the presence of 1-hydroxypyrene in the urine of health professionals with signs and symptoms related to occupational exposure to surgical smoke and to determine the relationship between 1-hydroxypyrene levels in urine at the end of a shift and the use of personal protective equipment.

Background

The human body metabolizes and eliminates PAHs via the kidneys through the metabolite 1-hydroxypyrene (1-OHP), which is detectable in the urine (García-García et al., 2022). The concentration of this metabolite in urine can depend on the metabolic activity at the point of entry into the organism and its distribution in the human body (Jongeneelen, 2014). Due to the simplicity and sensitivity of its analysis, and the speed with which it can be done (Liu et al., 2021), 1-OHP has been used as one of the main biomarkers of occupational exposure to PAHs.

PAHs are a class of persistent organic compounds that can pose significant risks to human health. These compounds can enter the human body through inhalation, ingestion of contaminated food, or dermal absorption (Sampaio et al., 2021; Shi et al., 2021).

PAHs are also recognized for their potential toxicity, as they are considered carcinogenic (Olsson et al., 2022). The Association of periOperative Registered Nurses (AORN) and the Occupational Safety and Health Administration (OSHA) recommend the use of personal protective equipment (PPE) and collective protective equipment (CPE) to protect professionals from the risks of surgical smoke exposure. CPE includes surgical smoke evacuation systems, and PPE includes N95 or FFP2 respirators. In addition to respirators, using personal protective eyewear is also recommended during exposure to surgical smoke to prevent the occurrence of signs and symptoms of eye problems (AORN, 2017; Caus et al., 2023; OSHA, 2024). Because of the nature of the components of surgical smoke, it is crucial to implement strict regulations and quality control measures to limit human exposure and raise awareness of the risks in order to mitigate the adverse effects on human health (Alhamdow et al., 2021; Heroor et al., 2022).

Research questions

Do professionals exposed to surgical smoke have signs and symptoms associated with the concentration levels of 1-OHP in their urine? Does the use of PPE reduce the concentration levels of 1-OHP in the urine of professionals exposed to surgical smoke?

Methodology

This is a cross-sectional field study, conducted in the surgical unit (SU) of a hospital providing high-complexity care in southern Brazil. Data collection took place from January to March 2018, during the day shift.

A total of 77 health professionals worked in the SU, including 36 nursing technicians and assistants, 10 nurses, 8 resident nurses, 18 anesthesiologists, and 13 resident anesthesiologists. All those exposed to surgical smoke, including nursing technicians, nurses, anesthesiologists, and resident anesthesiologists, who worked during the day shift were invited to participate in the study. Health professionals who were exposed to surgical smoke in a different workplace, who worked the night shift, or who were on any type of leave during the data collection period were excluded.

Forty health professionals working in the SU met the established inclusion criteria. Of these, four nursing staff members refused to participate, and one worked in a SU of another institution during the night shift. The physicians and resident anesthesiologists declined the invitation to participate in the study. Thus, the final sample of participants consisted of 21 nursing staff members, referred to as Group 1 (G1).

This group of surgical smoke-exposed professionals was compared with a control group consisting of other health professionals (nurses and nursing technicians) not exposed to surgical smoke during their work. This group included 30 professionals and was referred to as Group 2 (G2).

An instrument was developed by the investigators to assess the sociodemographic and occupational characteristics of the participants. It included the following variables: age, gender, smoking status, presence of chronic illnesses, and duration of use of electric scalpels during surgical procedures.

To determine the presence of 1-OHP, the metabolite

eliminated in the urine following exposure to PAHs, participants were instructed to collect a 15 ml urine sample at the beginning of their work shift (before occupational exposure to PAHs), and a second 15 ml urine sample at the end of the work shift (after occupational exposure to PAHs).
The collected urine samples were placed in plastic containers with lids, coded, and placed in thermal boxes with ice for shipment to the laboratory. Once there, they were stored in a freezer at a temperature of -18°C until the time of analysis.
To determine the presence of 1-OHP, the sample preparation method was as follows: 2 ml of 0.1 M sodium phosphate buffer was added to 5 ml of urine. The pH of the mixture was adjusted to 5 with a 0.1 M hydrochloric acid solution (781 pH/Ion Meter, Metrohm, Switzerland). Next, 25 µL of β-glucuronidase enzyme (2500 U) was added and, after homogenization, the mixture was incubated at 37°C for 16 hours with constant stirring at 210 rpm (Q826M20, Quimis, Brazil). After the incubation period, the samples were preconcentrated using C18/22% solid phase extraction cartridges (500 mg/6 ml) (Applied Separations, Allentown). The eluate was filtered through a 0.2 µm pore size membrane (Minisart RC 15, Sartorius Stedim Biotech, Germany) and injected into the chromatography system. For quantitative purposes, an analytical curve was prepared by adding a standard solution to a pool of urine from unexposed individuals (n = 6) using the same sample preparation protocol. The 1-OHP stock standard solution (Sigma Aldrich, Madrid, Spain) was prepared with a concentration of 100 µg L-1 in methanol. The final concentrations obtained were 0.025; 0.05; 0.25; 0.5; 1; 5 and 10 µg L-1 (Faria & Della Rosa, 2004).
Chromatographic analyses were conducted on a "20A series Prominence" high-performance liquid chromatography (HPLC) system (Shimadzu, Kyoto, Japan) and an "RL-10AXL" fluorescence detector (emission at 388 nm and excitation at 242 nm). The tests were performed using a "ZORBAX Eclipse XDB-C18 Analytical" HPLC column (250 × 4.6 mm, 5 µm; Agilent, USA) maintained at 40 ºC. The mobile phase consisted of methanol and ultrapure water at a flow rate of 1.0 mL/min. The linear elution gradient was as follows: 70% methanol (0 - 5 minutes), 95% methanol (5 - 10 minutes), and 70% methanol (10.1 - 15 minutes). The sample injection volume was 20.0 µL. Data acquisition and processing were performed using LC Solution software (Shimadzu, Kyoto, Japan). Linearity (n = 3), precision at low, medium, and high concentrations (n = 6), and recovery at three levels (n = 3) were evaluated. The limit of quantitation (LoQ) was determined as the lowest concentration point on the curve, and the limit of detection (LoD) was evaluated based on the signal-to-noise ratio.
To account for probable metabolic differences between participants, the clinical analyses of the metabolite 1-OHP were adjusted based on creatinine amounts.
To determine the signs and symptoms reported by the professionals exposed to surgical smoke, the following signs and symptoms were included in the questionnaire: vomiting, dizziness, nasopharyngeal lesions, watery eyes, eye irritation, irritation of other mucous membranes (mouth/nose), sneezing and nasal congestion, foreign body sensation in the throat, burning sensation in the throat, headache, nausea, and weakness.
Data were also collected on the use of PPE, such as surgical masks, N95 respirators, and personal protective eyewear, and CPE, such as surgical smoke evacuation systems.
The time spent using electric scalpels during surgical procedures was assessed using a stopwatch that was turned on with each use of the scalpel and turned off when the surgeon stopped using it. This procedure was performed by the investigators in the operating rooms where the professionals who agreed to participate in the study were working.
Data were organized and analyzed using IBM SPSS Statistics software, version 20.0. The Shapiro-Wilk test was used to assess the normality of the data, and the mean and standard deviation were calculated to describe the concentrations of the metabolite 1-OHP. The paired samples t-test was used to compare the means obtained at the beginning and end of the shift. A 95% confidence interval was used in tests to compare variables, with $p <$ 0.05 considered statistically significant (Besson, 2020). Fisher's exact test and Mann-Whitney test were used to analyze the association of independent variables between G1 and G2. Pearson's correlation was used to compare 1-OHP with the total time spent using the electric scalpels. The presence or absence of signs and symptoms was analyzed using Spearman's correlation test, followed by Poisson regression analysis to evaluate the predictive model for the presence of signs and symptoms associated with surgical smoke exposure. Multivariate regression was performed to evaluate the multiple interactions between signs and symptoms, use of PPE, and 1-OHP concentration levels in urine at the end of the shift (Besson, 2020).
All participants signed an informed consent form when they agreed to participate in the study, which was approved by the Human Research Ethics Committee under CAAE No. 46229915.0.0000.5231.

Results

Table 1 shows the sociodemographic description of the two groups of health professionals who participated in our study.

Table 1

Sociodemographic characteristics of G1 and G2 (n = 51)

Variables	G1 (*n* = 21)	G2 (*n* = 30)	*p*-value
Age (in years)	39 (± 10.62) *	26 (± 5.85) *	< 0.045
Gender			
Female	18 (41.9) ‡	25 (58.1) ‡	0.570§
Male	3 (37.5) ‡	5 (62.5) ‡	
Smoking status			
No	19 (40.4) ‡	28 (59.6) ‡	0.549§
Yes	2 (50.0) ‡	2 (50.0) ‡	
Chronic illness			
No	19 (41.3) ‡	27 (58.7) ‡	
Yes	2 (40) ‡	3 (60) ‡	0.669§

Note. * = Mean ± standard deviation; ‡ = Percentage; § = Fisher's exact test.

The concentrations of the metabolite 1-OHP in the urine samples of G1 did not show any significant differences when comparing the measurements taken at the beginning and the end of the work shift. The concentration of 1-OHP was not influenced by age or gender.

During data collection, the types of surgery observed by the investigators were mostly abdominal surgery (47.6%), thoracic surgery (28.6%), and other surgery in various body sites (23.8%). The results showed that there was no effect of the surgical site on the increase in 1-OHP concentration levels at the end of the work period ($p = 0.868$).

The analysis of the interaction between the measured signs and symptoms and the exposure revealed a positive correlation using Spearman's correlation coefficients between dizziness and the following variables: headache ($p = 0.007$), nausea ($p = 0.015$), vomiting ($p = 0.011$), watery eyes ($p = 0.005$) and weakness ($p = 0.000$) in G1. Regarding PPE, all professionals in G1 used a surgical mask and one of them reported using an N95 respirator. In addition, 38.1% of the professionals wore personal protective eyewear. Eye irritation was observed in professionals who did not wear personal protective eyewear ($p = 0.09$). None of the G1 professionals made use of the surgical smoke evacuation system.

The interaction between exposure and the main signs and symptoms was analyzed using Poisson regression, with adjustment for foreign body sensation in the throat and irritation of other mucous membranes. According to this predictive model, G1 exposure to surgical smoke increased the risk of presenting signs and symptoms by 1.56 times ($p = 0.000$). The presence of a foreign body sensation in the throat was considered the cutoff point for defining the adjustment model, while irritation of other mucous membranes contributed to a 1.20 increase in the risk of presenting other signs and symptoms associated with surgical smoke exposure ($p = 0.013$), as shown in Table 2.

Table 2

Association between exposure and symptoms of foreign body sensation in the throat and irritation of other mucous membranes in surgical smoke-exposed professionals based on the Poisson regression model.

Variables	Coefficient B	95% CI	*p*-value
Intercept	1.569	1.416 – 1.739	0.000*
Foreign body sensation in the throat	0.773	0.596 –1.003	0.053
Irritation of other mucous membranes	1.208	1.040 – 1.403	0.013*

Note. CI = Confidence interval; *$p < 0.05$

The investigators also noted that the higher the levels of 1-OHP in the urine, the greater the likelihood of developing signs and symptoms, which in this model were represented by the sensation of a foreign body in the throat. When 1-OHP levels reached their maximum value of 0.16 in this group, the risk of symptoms was 23.98 times greater. On the other hand, the use of personal protective eyewear proved to be a protective factor, reducing the risk of signs and symptoms by 13% (p-value 0.015). A multivariate linear regression, shown in Table 3, was performed to analyze the interaction between the different concentrations of 1-OHP in urine at the end of the work shift and the main PPE used - personal protective eyewear.

Table 3

Association between 1-hydroxypyrene levels at the end of the shift and the use of personal protective eyewear *in surgical smoke-exposed professionals based on the multiple linear regression model.*

Variables	Coefficient B	95% CI	*p*-value
1-OH µL (0.01)	0.036	0.002 – 0.7460	0.032*
1-OH µL (0.03)	0.060	0.005 – 0.755	0.029*
1-OH µL (0.04)	0.131	0.021 – 0.808	0.029*
1-OH µL (0.05)	0.470	0.113 – 1.961	0.300
1-OH µL (0.07)	0.617	0.161 – 2.362	0.481
1-OH µL (0.08)	1.402	0.390 – 5.041	0.605
1-OH µL (0.09)	2.389	0.594 – 9.608	0.220
1-OH µL (0.10)	4.276	1.018 – 17.960	0.047*
1-OH µL (0.11)	10.676	2.034 –56.029	0.005*
1-OH µL (0.16)	23.986	1.197 – 480.743	0.038*
Foreign body sensation	0.388	0.560 – 2.680	0.337
Use of personal protective eyewear	0.130	0.025 – 0.678	0.015*

Note. CI = Confidence interval; $^*p < 0.05$

Discussion

Our study is a pioneer in its field for detecting the presence of PAH metabolites in health professionals with occupational exposure to surgical smoke and assessing them in their workplaces.

PAHs, which we assessed through the analysis of the metabolite 1-OHP, are classified by the International Agency for Research on Cancer (IARC) as carcinogenic substances that can potentiate or generate the development of disordered cell growth. This agency considers that there are no safe levels for exposure to these substances and recommends a policy based on 100% avoidance (IARC, 2016).

Once in the human body, some PAHs are rapidly dissolved and transported throughout the body, mainly in adipose tissues, and some are eliminated. However, when they are associated with respirable particles, PAHs can take weeks to be eliminated (Pereira Netto et al., 2000). This justifies the decrease of the metabolite in the urine of G1 professionals and explains the development of signs and symptoms related to surgical smoke exposure.

Exposure to PAHs has an occupational exposure limit of 0.2 mg/m3, based on an average of 8 hours of exposure. Even at low levels, these substances can cause signs and symptoms in exposed individuals, such as skin and respiratory tract irritation, coughing, sore throat, dermatitis, eye and skin redness, and abdominal pain (Caus et al., 2023; Zhang et al., 2021).

The correlation between dizziness and variables such as headache, nausea, vomiting, watery eyes, and weakness may be a consequence of surgical smoke exposure (Caus et al., 2023; Zhang et al., 2021). However, it is important to consider that the amount of particles inhaled by professionals, the type of chemical compounds present in the smoke, the duration of exposure, and individual susceptibility can directly influence the intensity and severity of signs and symptoms (Bieniek et al., 2023). For this reason, it is recommended the installation of surgical smoke evacuation systems as CPE in operating rooms, as well as the use of N95 or FFP2 respirators and personal protective eyewear as PPE (Manoel Netto et al., 2021; Yu et al., 2022). These measures will minimize professionals' exposure to the risks generated by surgical smoke.

In the operating rooms where our study was conducted, there were no surgical smoke evacuation systems, and the use of N95 respirators and personal protective eyewear was not considered a habit among professionals, despite being recommended as PPE. On the other hand, according to the data collected, the professionals who used this type of PPE also had complaints, signs, and symptoms. Thus, the effectiveness of PPE as a barrier to surgical smoke remains to be fully demonstrated. Nevertheless, the N95 respirator offers a better fit to the face compared to the simple surgical mask, which allows more smoke to enter through the openings around the face (Leachi et al., 2022; Manoel Netto et al., 2021).

1-OHP was also found in the urine of G2 professionals, indicating that other health professionals, besides SU professionals, may also be exposed to the components of surgical smoke. This exposure can occur during the performance of their work but also in their daily activities outside the hospital environment. If continuous, exposure to surgical smoke components can increase the possibility of developing occupational diseases, given that some PAHs have cumulative effects on the human body (Mallah et al., 2022).

The literature shows that exposure to PAHs can cause cardiovascular (Mirzababaei et al., 2021) and respiratory damage to health professionals. Therefore, the presence of the metabolite 1-OHP in the urine of these professionals serves as a warning sign that they are exposed to PAHs in surgical smoke and may face a potential health risk daily (Mallah et al., 2022).

Workplace-based studies have limitations, such as sample size, due to the small number of exposed individuals who meet the pre-established criteria for the research and agree to participate and provide samples. Besides this limitation, and considering the target compound, our study was also limited by the fact that it did not assess the ability of PAHs to be absorbed through the skin, which may influence the final biomonitoring values. Also, the elimination time of the metabolite 1-OHP may vary according to the metabolic rate of each organism. Therefore, for a more comprehensive and robust understanding of the results and extrapolation of the data, we recommend that additional studies be conducted on oxidative stress induced by components of surgical smoke.

Conclusion

Our study shows that the higher the levels of 1-OHP in urine, the greater the likelihood of developing signs and symptoms. In addition, the use of personal protective eyewear proved to be a protective factor, reducing the risk of the development of signs and symptoms.

Author Contributions
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Writing - review & editing: Lima, H. F., Rocha, A. F., Peixe, T. S., Ribeiro, R. P.

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