Observational Study

Journal of INTERNATIONAL MEDICAL RESEARCH

Journal of International Medical Research
2025, Vol. 53(6) 1–14

DOI: 10.1177/03000605251347553
journals.sagepub.com/home/imr
Sage

Surgical smoke-related occupational injuries among medical professionals in the operating room

Chen Fengxia[1], Dexiang Jin[2] and Ailing Lian[3]

Abstract

Objective: The use of energy devices during surgery can cause the spread of surgical smoke into the operating room. The concentration of smoke particles during laparoscopic surgery is higher than that during open surgery. This study aimed to quantify polycyclic aromatic hydrocarbons during laparoscopic surgery and evaluate the carcinogenic risks to healthcare workers, as the current relevant data are insufficient.

Methods: This prospective observational study collected and classified surgical smoke generated during laparoscopic surgery. Quantitative and qualitative analyses of polycyclic aromatic hydrocarbons were performed using gas chromatography–mass spectrometry.

Results: Multiple types of polycyclic aromatic hydrocarbons were generated during laparoscopic surgery. The polycyclic aromatic hydrocarbon concentrations remained below the carcinogenic risk levels in both laparoscopic liver cancer surgery and rectal cancer resection procedures.

Conclusion: The deposition pattern and concentration of polycyclic aromatic hydrocarbons generated during laparoscopic liver and rectal cancer resection surgeries in the human respiratory tract are different. The potential toxicity of polycyclic aromatic hydrocarbons in the smoke to the health of healthcare workers should not be ignored.

Keywords

Surgical smoke, carcinogenic risk, occupational exposure, laparoscopic surgery, operating room

Date received: 9 January 2025; accepted: 1 May 2025

[1]Nursing School, North Henan Medical University, China
[2]Operating Room, The First Affiliated Hospital of Harbin Medical University, China
[3]Operating Room, The First Affiliated Hospital of Harbin Medical University, China

Corresponding author:
Ailing Lian, Operating Room, The First Affiliated Hospital of Harbin Medical University, 23 Postal Street, Nangang District, Harbin, 150000, China.
Emails: 776702705@qq.com; LianAiling@hrbmu.edu.cn

Introduction

During surgical operations, energy devices such as electric knives, lasers, and ultrasonic scalpels are commonly used to separate tissues and seal blood vessels. During this process, cell decomposition, rupture, and evaporation occur, releasing surgical smoke into the air.[1] Surgical smoke is composed of 95% water or steam and 5% particles.[2] These particles vary in size and can deposit onto different parts of the human respiratory system: particles with a size >5 μm deposit on the nasopharynx wall, those with a size between 2 and 5 μm enter the trachea and bronchi, and those smaller than 1 μm, similar to gas molecules, can penetrate downward into the alveoli and further transfer to cellular tissue and/or the circulatory system.[3,4]

Inhaling particulate matter (PM) may have adverse effects on human health due to the various toxic compounds attached to its surface, among which polycyclic aromatic hydrocarbons (PAHs) are considered to be the most cytotoxic, mutagenic, and carcinogenic organic chemicals.[5] Studies have shown that PAHs promote the production of large amounts of reactive oxygen species, leading to oxidative stress in the cardiovascular and pulmonary systems, and may cause DNA damage.[6] Short-term exposure to PAHs may lead to eye and skin irritation, nausea, and vomiting, whereas long-term exposure may lead to liver and kidney damage and increased risk of lung cancer, skin cancer, and bladder cancer as well as gene mutations, cell damage, and increased rates of cardiovascular and pulmonary mortality.[7] Epidemiological studies have shown that PAHs exert adverse effects on female reproduction and fetal development and are associated with several later childhood issues, such as low IQ, behavioral problems, allergies, or asthma.[8,9]

Although the toxic effects of surgical smoke are not typical, relevant studies have revealed that surgical smoke exhibits potential mutagenicity on standard Salmonella particles, embryotoxicity on human embryonic cells, and inhibitory effects on the differentiation of myocardial cells.[10,11] Compared with open abdominal surgery, the surgical smoke generated from laparoscopic surgery is confined to the abdominal cavity and discharged when necessary, which results in even higher particle concentrations at the time of release.[12] This also indicates that healthcare workers near the operating table may be exposed to higher concentrations of toxic PAHs. However, there is still insufficient data to quantify the PAHs in laparoscopic surgical smoke and the potential carcinogenic risk they pose to healthcare workers. Therefore, the purpose of this study was to analyze the distribution and concentration of 16 PAHs adhering to particles in laparoscopic surgical smoke in the respiratory system, which have been listed as priority pollutants by the US Environmental Protection Agency.[13] The total toxic equivalent concentration (ΣTEQ) was calculated based on the toxicity equivalency factor (TEF) of each PAH to evaluate the potential cancer risk for the medical staff in the operating room.[14] Considering that the liver produces more particles than other tissues,[15] this study collected the smoke generated during laparoscopic liver resection as a sample. In addition to solid organs, we sought to understand the status of PAHs produced by hollow organs. Therefore, we also collected the smoke generated during laparoscopic rectal cancer surgery. This study has been approved by the Institutional Review Board (2022055) of the hospital, and the participants provided written informed consent.

Materials and methods

Study design

This is a cross-sectional study conducted in a large teaching hospital in northern China,

which has been approved by the hospital's ethics committee. It was not possible to calculate the minimum sample size for this study, and the study was mainly terminated when the color of the sampler filter membrane changed visibly. This study serves as a pilot for further research. All patient details have been de-identified.

The study was conducted in accordance with the Helsinki Declaration.

Air sampling

The sampler (Model 20-800, Thermo-Andersen, Atlanta, GA, USA) used to collect laparoscopic surgical smoke was a multi-stage porous cascade impactor for nonbiological environmental sampling. It has eight impact plates, each with a diameter of 81 mm, and glass fiber filter membrane, as shown in Figure 1. The sampler classifies the particles collected based on the deposition of atmospheric particles in the human respiratory system through aerodynamic simulation. The cutoff diameters of each stage are 0.43, 0.65, 1.1, 2.1, 3.3, 4.7, 5.8, and 9 μm. The human respiratory system simulated by the sampler is shown in Figure 2. PM4.7–10 mainly exists in the nasal pharynx, whereas PM1.1–4.7 and PM < 1.1 can enter the tracheobronchial and alveolar regions of the human respiratory system, respectively. Surgical smoke enters the sampler and is collected on the surface of the filter membranes of each stage through small holes with different diameters on the impact plate. The sampler was disinfected with 75% alcohol and flow-calibrated before sampling. The sampling flow rate was set at 28.3 L/min, and the glass fiber filter membranes were heated at 480°C to remove possible contaminants.

Sample collection

All surgical samples were collected in the same operating room at the same cleanliness level of the hospital (level 7 cleanliness, with a dust particle count greater than 35,000 particles/m^3 but less than or equal to 350,000 particles/m^3 and a size $\geq$0.5 μm). The environment during surgery was maintained at a temperature of 21°C–24°C and humidity of 30%–40%.

Purpose sampling was used to select participants from a large teaching hospital between December 2022 and February 2023. The inclusion criteria were as follows: (a) patients underwent elective laparoscopic hepatectomy or laparoscopic rectal resection; (b) surgery involving general anesthesia; (c) provision of informed consent for study participation. The exclusion criteria were as follows: (a) patients converted to laparotomy during the operation; (b) occurrence of a life-threatening situation during the operation, such as massive bleeding; (c) the operation duration was >5 h.

The sampler was placed under the patient's head on the surgical table.

Figure 1. Sampler and all levels of impact plate.

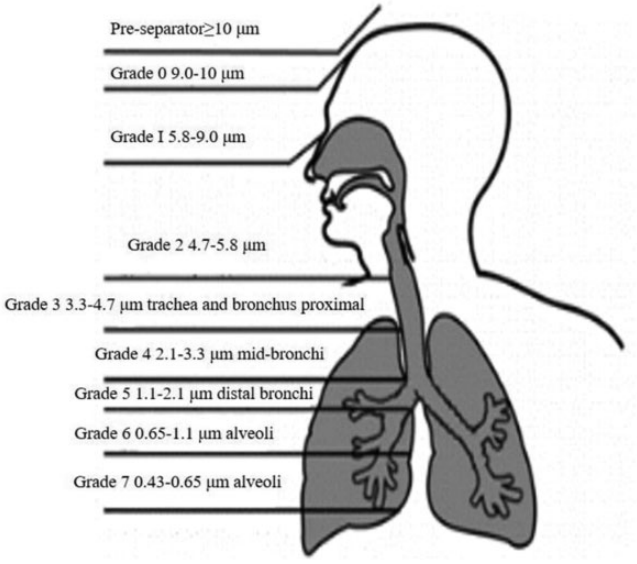

Figure 2. Particle size classification and deposition location in the human respiratory system.

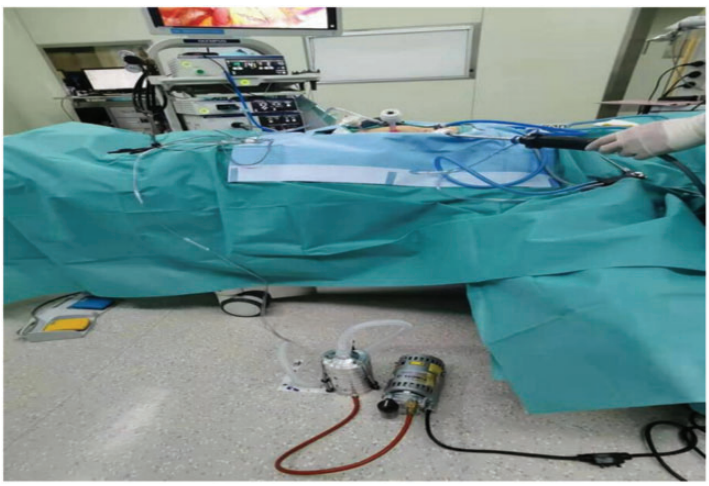

Figure 3. Method of sampling.

A disposable sterile straw was connected to the puncture needle exhaust port by the scrub nurse, whereas the other end was connected to the sampling line by the experimenter, as shown in Figure 3. After the surgery began, the surgeon opened the valve of the puncture needle by 1/2 to 2/3 to ensure that the surgical smoke could be drawn into the sampler and maintain the pneumoperitoneum pressure between 12 and 14 mmHg, collecting the smoke until the end of the surgery. This study was reported in accordance with the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines.[16]

PAH analysis

Sample preconditioning. The filter membranes were cut into small pieces using scissors and placed in 10-mL glass centrifuge tubes with stoppers. The tools used for cutting and transferring the membrane samples were rinsed with a mixture of n-hexane and dichloromethane. In each centrifuge tube, 9 mL of a mixed solution of n-hexane and dichloromethane (v/v: 1/3) and 100 μL of PAH surrogate standards (including naphthalene-d8, phenanthrene-d10, and pyrene-d10) at a concentration of 200 ng/mL were added sequentially, vigorously vortexed, and then subjected to ultrasonic extraction in the dark for 60 min. The two-stage filter membranes (0.43–0.65 and 0.65–1.1 μm) from the surgical samples were extracted twice using the same method. The tubes containing the extracts were subjected to centrifugation at 3500 rpm for 5 min, and the supernatant was filtered through a 0.45-μm nylon filter. Blank controls were set up by processing filter membranes that were placed in the sampler but not exposed to surgical smoke using the same method as for the samples to correct for any system errors.

After extraction, the sample solutions were transferred to a nitrogen blow tube and then evaporated until a volume of 100 μL under nitrogen gas. The extracted samples were stored in a −20°C freezer until they were analyzed using instrumental methods.

Sample testing. The samples were qualitatively and quantitatively analyzed using gas chromatography–mass spectrometry in the selected ion monitoring mode. The chromatographic column used was an HP-5 (30 m × 250 μm × 0.25 μm). The temperature program was initially set at 80°C for 3 min, after which the temperature was increased at a rate of 10°C/min to 200°C and held for 4 min, followed by an increase to 260°C at a rate of 12°C/min, where it was held for 1 min. Finally, the temperature was increased to 310°C at a rate of 15°C/min and held for 8 min. The PAH standard curves were prepared with concentrations of 5, 10, 50, 100, 200, and 500 ng/mL. The retention times and characteristic ions of PAHs are shown in Table 1. The collected filter membranes from rectal and liver surgeries were labeled as 1-1, 1-2…1-9, and 2-1, 2-2,…2-9, respectively. The chromatograms of the 500 ng/mL PAH standard and the actual sample (sample 2–9) are shown in Figures 4 and 5, respectively. The concentrations of the second extraction samples were lower than those of the first extraction samples by <30%, indicating good extraction efficiency. All sample concentrations were blank-corrected, and the final concentrations were expressed as absolute concentration (ng), air volume concentration (ng/m^3), and per-operation concentration (ng/operation). The formulas for calculating the PAH air volume concentration (ng/m^3) and per-operation PAH concentration (ng/operation) were as follows:

Table 1. Retention time and characteristic ions of 16 polycyclic aromatic hydrocarbons.

Organic compounds	Retention time (min)	Parent ion (m/z)	Fragment ion (m/z)
Naphthalene	7.56	128	127
Acenaphthylene	11.67	152	151
Acenaphthene	12.06	153	154
Fluorene	13.31	166	165
Phenanthrene	15.88	178	176
Anthracene	15.99	178	176
Fluoranthene	20.88	202	200
Pyrene	21.78	202	200
Benzo[a]anthracene	25.47	228	226
Chrysene	25.65	228	226
Benzo[b]fluoranthene	28.10	252	250
Benzo[k]fluoranthene	28.13	252	250
Benzo[a]pyrene	28.80	252	250
Benzo[1,2,3-cd]pyrene	31.43	276	274
Dibenz[a,h]anthracene	31.59	278	276
Benzo[g,h,i]pyrene	32.32	276	274

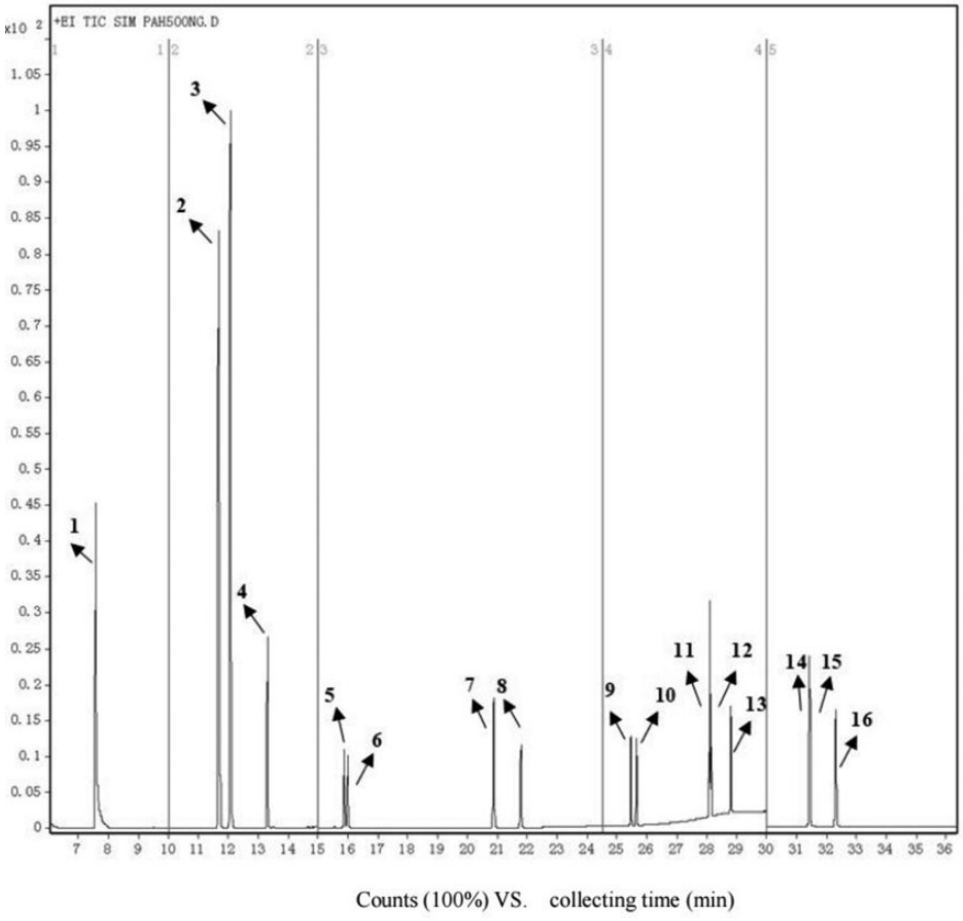

Figure 4. TIC chromatogram of polycyclic aromatic hydrocarbon standard solution (500 ng/mL). TIC: total ion chromatogram.

$$\text{Air volume concentration } (\text{ng/m}^3) = \left(\text{sample concentration (ng)}/\text{air volume}(\text{m}^3)\right) \times 10^6$$

$$\text{Per-operation concentration (ng/operation)} = \left(\text{sample concentration (ng)}/\text{sample blank volume}\,(\text{m}^3)\right) \times \text{operation volume}\,(\text{m}^3)$$

$$\text{PAH air volume concentration} = \text{Ci/V} \quad (1)$$

$$\text{Per-operation PAH concentration} = \text{Ci/N} \quad (2)$$

In the above formulas, Ci, V, and N represent the absolute concentration of PAHs at the i^{th} particle size level (ng), volume of collected air (m^3), and number of surgical operations, respectively.

Results

Sample concentration analysis

The sampling period was from December 2020 to March 2021, during which surgical

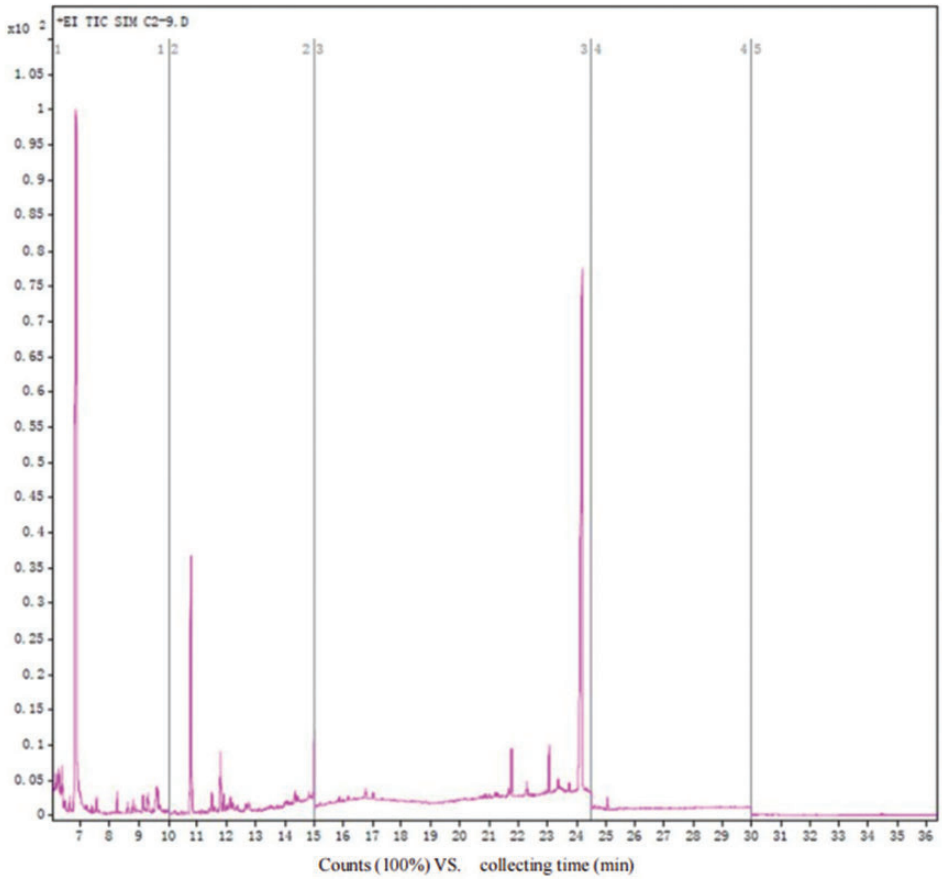

Figure 5. TIC chromatogram of actual samples (2–9). TIC: total ion chromatogram.

smoke generated from 16 laparoscopic colorectal resections and 19 laparoscopic liver resections was collected. The air volumes collected were 70.467 and 84.4189 m^3, respectively. The concentrations of PAHs (ng/m^3) in the two types of surgical smoke are shown in Table 2.

With the exception of naphthalene and dibenz[a,h]anthracene, the remaining 14 PAHs were found in laparoscopic surgical smoke. In colorectal surgery, acenaphthene had the highest concentration (0.422 ng/m^3), followed by fluoranthene (0.34757 ng/m^3), pyrene (0.3107 ng/m^3), benzo[b]fluoranthene (0.25436 ng/m^3), anthracene (0.214 ng/m^3), and phenanthrene (0.206873 ng/m^3). In liver surgery, acenaphthene also had the highest concentration (1.249858 ng/m^3), followed by chrysene (0.4469 ng/m^3), benzo[b]fluoranthene (0.3367 ng/m^3), pyrene (0.229018 ng/m^3), and benzo[k]fluoranthene (0.1221 ng/m^3). The total concentration of PAHs produced during colorectal surgery was 2.399 ng/m^3, with concentrations in the nasal pharynx, tracheobronchial region, and alveoli of 0.448, 0.415, and 1.536 ng/m^3, respectively. The total concentration of PAHs produced during liver surgery was 2.819 ng/m^3, with concentrations in the nasal pharynx, tracheobronchial region, and alveoli of 0.796, 0.270, and 1.752 ng/m^3, respectively. The deposition patterns of

Table 2. Concentrations of polycyclic aromatic hydrocarbons in laparoscopic surgical smoke.

Organic compounds	Concentration during colorectal surgery (ng/m^3)				Concentration during liver cancer surgery (ng/m^3)			
	Nasopharynx	Tracheobronchial	Alveolar	Total	Nasopharynx	Tracheobronchial	Alveolar	Total
Nap	ND	ND	ND	–	ND	ND	ND	—
Acy	ND	ND	0.422	0.422	0.144	0.015	1.091	1.250
Ace	ND	ND	0.012	0.012	ND	ND	0.059	0.059
Fl	ND	ND	0.052	0.052	0.000	ND	0.031	0.031
Phe	0.000	ND	0.206	0.206	ND	0.001	0.081	0.082
Ant	ND	ND	0.214	0.214	0.000	ND	0.004	0.003
Fla	0.108	0.234	0.005	0.347	0.004	0.006	0.082	0.092
Pyr	0.014	ND	0.297	0.311	0.000	0.007	0.222	0.229
BaA	ND	ND	0.101	0.101	ND	ND	0.002	0.002
Chr	0.140	0.016	ND	0.156	0.372	ND	0.075	0.447
BbF	ND	ND	0.008	0.008	0.061	ND	0.013	0.073
BkF	0.051	0.099	ND	0.150	0.001	0.060	0.061	0.122
BaP	ND	ND	0.053	0.053	0.005	ND	ND	0.005
IDP	0.097	0.065	0.092	0.254	0.197	0.106	0.034	0.337
DBahA	ND	ND	ND	—	ND	ND	ND	—
Bghip	0.038	ND	0.074	0.111	0.011	0.076	ND	0.087
Total	0.448	0.415	1.536	2.399	0.796	0.270	1.753	2.819

ND: not detected; Nap: naphthalene; Acy: acenaphthylene; Ace: acenaphthene; Fl: fluorene; Phe: phenanthrene; Ant: anthracene; Fla: fluoranthene; Pyr: pyrene; BaA: benzo[a]anthracene; Chr: chrysene; BbF: benzo[b]fluoranthene; BkF: benzo[k]fluoranthene; BaP: benzo[a]pyrene; IDP: indeno[1,2,3-cd]pyrene; DBahA: dibenz[a,h]anthracene; BghiP: benzo[g,h,i]perylene.

both types of laparoscopic surgical smoke in the human respiratory system were similar, with the highest concentration in the alveoli, followed by the nasal pharynx, and the lowest in the tracheobronchial region.

As shown in Figure 6, although PAHs generated during laparoscopic surgery were predominantly deposited in the alveoli, there were differences in their distribution across particle size ranges. During colorectal surgery, PAHs were mainly present in particles with a size of 0.43–0.65 μm, with lower concentrations observed in particles smaller than 0.43 μm. In contrast, PAHs produced during liver surgery were distributed in larger particle size ranges, with the peak concentration observed in particles with a size of 0.65–1.1 μm and significantly higher concentrations observed in particles smaller than 0.43 μm compared with those observed during colorectal surgery. Additionally, liver surgery exhibited higher concentrations of PAHs in particles with a size of 4.7–5.8 μm.

As shown in Figure 7, the concentration of PAHs produced during liver surgery (12.5 ng/operation) was higher than that produced during colorectal surgery (11.3 ng/operation). The concentration of PAHs that can be deposited in the tracheobronchial region during colorectal surgery (1.83 ng/operation) was higher than that during liver surgery (1.20 ng/operation), whereas the concentration of PAHs that can be deposited in the nasal pharynx (3.54 ng/operation) and alveoli (7.79 ng/operation) during liver surgery was significantly higher than that during colorectal surgery (nasal pharynx (1.97 ng/operation) and alveoli (7.48 ng/operation)).

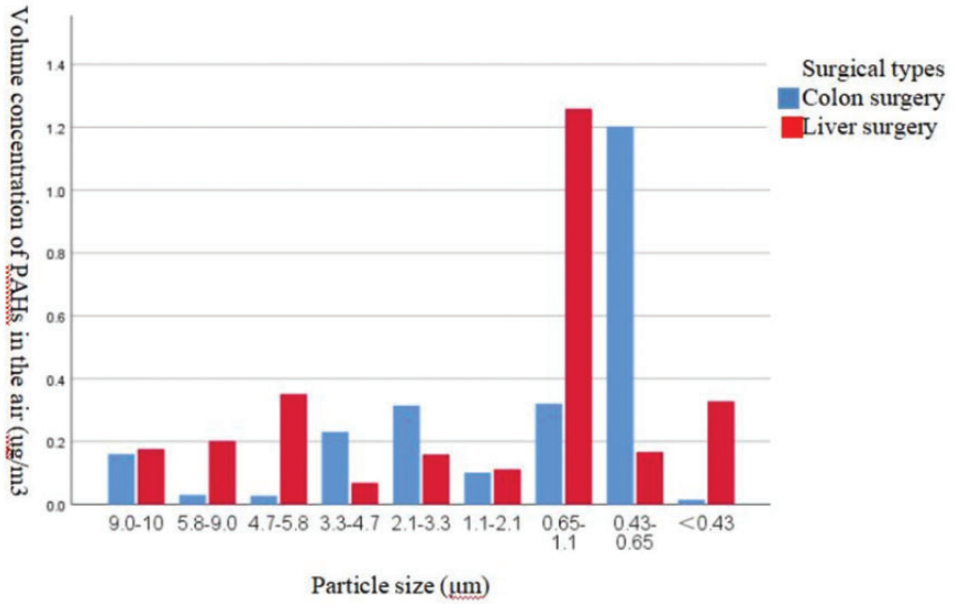

Figure 6. Characteristics of polycyclic aromatic hydrocarbon respiratory deposition in laparoscopic smoke.

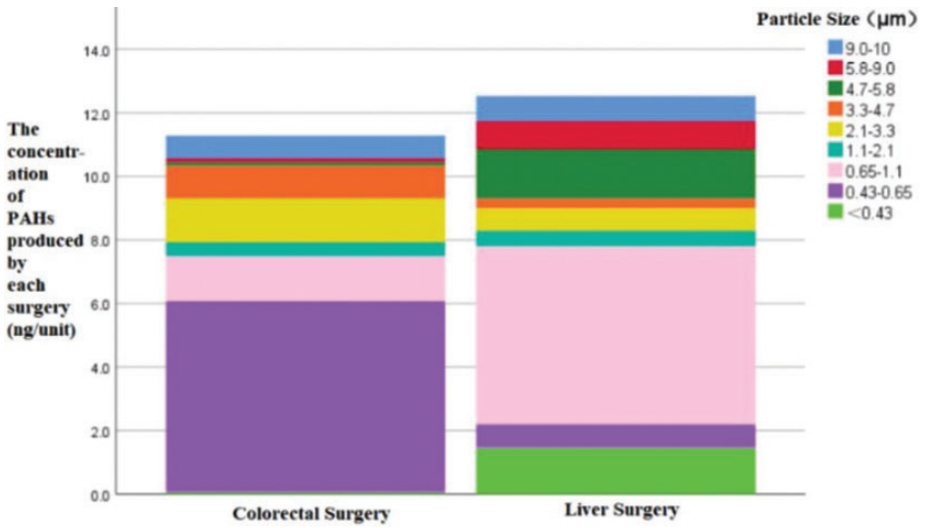

Figure 7. Concentration of polycyclic aromatic hydrocarbons produced per operation (ng per operation).

Carcinogenic toxicity equivalents

The TEF for each target compound was calculated relative to the carcinogenicity of benzo[a]pyrene, which was assigned a value of 1. The TEF data are shown in Table 3. Based on the TEF method, the total carcinogenic potential (ΣTEQ) of the PAHs in

Table 3. Toxic equivalence factors of compounds.

Organic compound	Toxic equivalence factor
Naphthalene	0.001
Acenaphthylene	0.001
Acenaphthene	0.001
Fluorene	0.001
Phenanthrene	0.001
Anthracene	0.01
Fluoranthene	0.001
Pyrene	0.001
Benzo[a]anthracene	0.1
Chrysene	0.01
Benzo[b]fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Benzo[a]pyrene	1
Indeno[1,2,3-cd]pyrene	0.1
Dibenz[a,h]anthracene	1
Benzo[g,h.j]pyrene	0.01

the surgical smoke particles was calculated according to the detected concentrations of each compound using the following formula:

$$\Sigma TEQ = \Sigma Ci \times TEFi \quad (3)$$

$$\Sigma TEQ = (C1 \times TEF1) + (C2 \times TEF2) + \cdots + (Cn \times TEFn)$$

where C1–Cn are the concentrations (ng/m^3) of each target compound detected in the surgical smoke particles and TEF1–Tn are the TEFs for each target compound.

The calculation results showed that the mean ΣTEQ of the 16 PAHs in rectal and liver surgeries were 0.0123 and 0.00726 ng/m^3, respectively. These values were below the World Health Organization standard (1 ng/m^3), indicating that the concentration of PAHs generated during these surgeries did not reach carcinogenic risk levels.

Discussion

In this pilot study, we collected the surgical smoke during laparoscopic hepatectomy or laparoscopic rectal resection as well as monitored the specific composition and amount of PAHs in surgical smoke. This is different from a previous study that focused on other composition in surgical smoke and surgery types.[17]

Overall, 14 of the 16 monitored PAHs were detected in the smoke generated during the two laparoscopic surgeries, including benzo[a]pyrene and indeno[1,2,3-cd]pyrene, which have been listed as human carcinogens or potential carcinogens by the International Agency for Research on Cancer (IARC).[18] Although the concentrations of these compounds were below the carcinogenic risk level, healthcare workers must remain vigilant.

This study showed that after inhaling PAHs, they could be deposited in large amounts in the alveoli, indicating that they easily participate in the metabolism of pulmonary tissue and enter the bloodstream. As healthcare workers are exposed to surgical smoke for decades, this finding raises concerns about their health. A study based on breast surgery expressed the same view. According to their results, the risk of cancer in surgeons and anesthetists exposed to PAHs in surgical smoke for 70 years was 117 and 270 times higher than that in the general population, respectively.[19]

In addition, although the health risks of exposure to surgical smoke are primarily determined by the toxicity of individual compounds, PAHs, especially low molecular weight PAHs (LMW-PAHs, containing 2–4 benzene rings) with high concentrations in the environment, may have synergistic effects on toxicity. These LMW-PAHs have not been given much attention because they are either nongenotoxic or have weak genotoxicity. Existing studies have indicated that LMW-PAHs such as anthracene and 1-methylanthracene can act as co-carcinogens with the carcinogenic PAH benzo[a]pyrene (B[a]P)[20,21]; a mixture of phenanthrene and fluorene can act

synergistically to cause oxidative damage and induce cell toxicity.[22] In addition to malignant tumors, exposure to LMW-PAHs is associated with the development of lung diseases such as asthma and chronic obstructive pulmonary disease.[23]

In this study, in both liver and colorectal surgeries, acenaphthene (containing three benzene rings) was the PAH with the highest concentration. A previous study reported that acenaphthene exerted mutagenic effects on *Salmonella typhimurium* in rats, and it could be oxidized by different forms of human P450 enzymes, which may have some implications for the study of their metabolism and their biological and toxicological significance in humans.[24,25] However, the carcinogenicity of acenaphthene has not been evaluated by the IARC. Thus, further research is needed to explore the toxic effects of these LMW-PAHs, which are abundant in surgical smoke, on human lung epithelial cells.

Furthermore, we found the existing studies analyzing the concentration of PAHs in smoke generated during open surgeries,[12,19,26] where naphthalene was the PAH with the highest concentration. For example, Claudio et al. collected smoke from 50 abdominal surgeries and detected naphthalene in 48 of them, except for the 2 laparoscopic surgeries.[27] This was contradictory to our results, as naphthalene was not detected in our samples.

We speculate that the reason for this difference may be the different surgical methods, such as open and laparoscopic surgeries. In the current study, the concentration of PAHs in laparoscopic liver surgery was higher but less toxic than that in laparoscopic gastrointestinal surgery, which may be due to the significant difference in the concentration of individual PAHs produced by the two surgeries. This may be related to various factors such as the surgeon's technique, target tissue, amount of bleeding, type of energy used, power used, duration of surgery, and the patient's body mass index.[3,26,28–30] As the current study is a pilot cross-sectional survey, we would control for some variables and analyze how they affect the surgical smoke production of PAHs in future studies, aiming to reduce the production of PAHs from the source.

This study also found that in rectal surgery, PAHs were mainly present in particles with a size of 0.43–0.65 μm, whereas in liver surgery, concentration peaks were observed in particles with a size of 0.65–1.1 and 4.7–5.8 μm, suggesting that PAHs in laparoscopic surgical smoke are more likely to adsorb on smaller particles and be deposited in the lower respiratory tract accompanied with respiratory movements, which may lead to occupational exposure for the medical staff during surgery, even though healthcare workers wear disposable surgical masks during surgeries. A study showed that the filtration efficiency of regular surgical masks for particles with a size of $\leq$4 μm was only 63.7%.[31] However, the concentration of PAHs attached to particles smaller than 4.7 μm was very high, indicating that most PAHs could still enter and be deposited in the lower respiratory tract along with surgical smoke particles.

This suggests that more strategies should be explored to reduce the medical staff's exposure to surgical smoke. The guideline from the Association of periOperative Registered Nurses (AORN) in the United States recommends ensuring at least 20 air changes per hour in operating rooms as well as equipping ultra-low particulate air filters and smoke evacuator systems specialized for minimally invasive surgeries. For high-risk surgeries that may have potential for aerosol transmission, N95 respirators are recommended.[32] However, there is no mandatory requirement for hospitals to use additional smoke evacuation devices; therefore, the decision of whether to purchase

and use these devices depends only on hospitals.

In China, the relevant technical specifications stipulate that the operating room should guarantee 12–24 air changes per hour based on different levels of cleanliness, with a minimum fresh air volume of 15–20 m^3/h per square meter; adjustments should be made according to whether electrosurgical devices are used during the surgery.[33] Many surgeons still use only the suction device as the sole smoke evacuation method, which involves using a general negative pressure suction device to suck smoke into another suction canister, which is not effective in removing surgical smoke. Some scholars have also attempted to use fixed-tube needles with balloons, maintaining the lowest possible intra-abdominal pressure and carbon dioxide levels during surgery, to reduce exposure risks[34,35] from the gas leakage caused by the pressure needle of the insufflation device used in laparoscopic surgeries. However, these methods face limitations in both clinical implementation and practical efficacy. Therefore, it is necessary to conduct more studies urging healthcare institutions to pay more attention to surgery smoke exposure and explore the effect of different prevention techniques.

Implications for nursing and health policy

Role-specific training programs and continuous education are needed to enhance surgical smoke exposure-related knowledge and practices among medical professions in operating rooms. Policies must support educational efforts and measures, ensuring that the operating room medical staff could balance patient care responsibilities with surgical smoke protection measures.

Limitations

First, due to time and resource constraints, the sample size for collecting surgical smoke was not sufficiently large, and we did not measure gaseous PAHs, which may have an impact on the final study results. Second, the PAH concentrations in our data showed the amount of surgical smoke adsorbed on all inhalable particles, without considering the diffusion of smoke in the environment and the filtering effect of protective devices. Further research should increase the sample size and focus on the impact of gaseous and fine particulate PAHs on healthcare workers.

Conclusion

During laparoscopic hepatectomy and laparoscopic rectal resection, various low-level PAHs may be produced, among which naphthalene has been detected with the highest concentration. PAHs in surgical smoke during these surgeries tend to deposit in the alveoli of the respiratory system, followed by the nasopharynx and the trachea and bronchi. The concentration of PAHs is higher in laparoscopic hepatectomy than in laparoscopic rectal resection, but they are less toxic in laparoscopic hepatectomy. PAHs in surgical smoke may pose long-term potential hazards to the health of healthcare workers, and it is recommended to adopt reasonable protective measures to reduce the associated risk.

Acknowledgements

We sincerely thank all patients who allowed researchers to collect surgical smoke in the operating room during their survey and all the members of our study team.

Author contributions

Ailing Lian: development of the original idea and study design. Chen Fengxia: operator, data collection, statistical analysis, and manuscript writing. Dexiang Jin: operator, data collection and organization.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of conflicting interests

The authors declare that they have no conflicts of interest in relation to this article.

Ethical considerations & disclosure

This study has been approved by the Ethics Committee of the First Affiliated Hospital of Harbin Medical University [2022055].

Funding

This work was supported by the Medical-Engineering Cooperation Fund of the China Primary Health Care Foundation [2022HX027], and the fund of the Science and Technology Department of Heilongjiang Province [2024ZX12C31].

ORCID iD

Chen Fengxia https://orcid.org/0009-0001-9187-0452

References

1. Fencl JL. Guideline implementation: surgical smoke safety. *Aorn J* 2017; 105: 488–497.
2. Ulmer BC. The hazards of surgical smoke. *Aorn J* 2008; 87: 721–738.
3. Limchantra IV, Fong Y and Melstrom KA. Surgical smoke exposure in operating room personnel: a review. *JAMA Surg* 2019; 154: 960–967.
4. Kim KH, Kabir E and Kabir S. A review on the human health impact of airborne particulate matter. *Environ Int* 2015; 74: 136–143.
5. Boström CE, Gerde P, Hanberg A, et al. Cancer risk assessment, indicators, and guidelines for polycyclic aromatic hydrocarbons in the ambient air. *Environ Health Perspect* 2002; 110: 451–488.
6. Kermani M, Rahmatinia T, Oskoei V, et al. Potential cytotoxicity of trace elements and polycyclic aromatic hydrocarbons bounded to particulate matter: a review on in vitro studies on human lung epithelial cells. *Environ Sci Pollut Res Int* 2021; 28: 55888–55904.
7. Kim KH, Jahan SA, Kabir E, et al. A review of airborne polycyclic aromatic hydrocarbons (PAHs) and their human health effects. *Environ Int* 2013; 60: 71–80.
8. Bolden AL, Rochester JR, Schultz K, et al. Polycyclic aromatic hydrocarbons and female reproductive health: a scoping review. *Reprod Toxicol* 2017; 73: 61–74.
9. Drwal E, Rak A and Gregoraszczuk EL. Review: polycyclic aromatic hydrocarbons (PAHs)-Action on placental function and health risks in future life of newborns. *Toxicology* 2019; 411: 133–142.
10. Gatti JE, Bryant CJ, Noone RB, et al. The mutagenicity of electrocautery smoke. *Plast Reconstr Surg* 1992; 89: 781–784. discussion 785–786.
11. Zhou R, Xia M, Zhang L, et al. Fine particles in surgical smoke affect embryonic cardiomyocyte differentiation through oxidative stress and mitophagy. *Ecotoxicol Environ Saf* 2021; 217: 112259.
12. Li CI, Pai JY and Chen CH. Characterization of smoke generated during the use of surgical knife in laparotomy surgeries. *J Air Waste Manag Assoc* 2020; 70: 324–332.
13. US EPA. Priority pollutant list, https://www.epa.gov/sites/default/files/201509/documents/priority-pollutant-list-epa.pdf (2014, accessed 22 March 2024).
14. Nisbet ICT and LaGoy PK. Toxic equivalency factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs). *Regul Toxicol Pharmacol* 1992; 16: 290–300.
15. Karjalainen M, Kontunen A, Saari S, et al. The characterization of surgical smoke from various tissues and its implications for occupational safety. *PloS One* 2018; 13: e0195274.
16. Von Elm E, Altman DG, Egger M; STROBE Initiative, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *J Clin Epidemiol* 2008; 61: 344–349.

17. Merajikhah A, Imani B, Khazaei S, et al. Impact of surgical smoke on the surgical team and operating room nurses and its reduction strategies: a systematic review. *Iran J Public Health* 2022; 51: 27–36.
18. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Some non-heterocyclic polycyclic aromatic hydrocarbons and some related exposures. *IARC Monogr Eval Carcinog Risks Hum* 2010; 92: 1–853.
19. Tseng HS, Liu SP, Uang SN, et al. Cancer risk of incremental exposure to polycyclic aromatic hydrocarbons in electrocautery smoke for mastectomy personnel. *World J Surg Oncol* 2014; 12: 31.
20. Brózman O, Novák J, Bauer AK, et al. Airborne PAHs inhibit gap junctional intercellular communication and activate MAPKs in human bronchial epithelial cell line. *Environ Toxicol Pharmacol* 2020; 79: 103422.
21. Bauer AK, Siegrist KJ, Wolff M, et al. The carcinogenic properties of overlooked yet prevalent polycyclic aromatic hydrocarbons in human lung epithelial cells. *Toxics* 2022; 10: 28.
22. Guo H, Huang Y, Wang H, et al. Low molecular weight-PAHs induced inflammation in A549 cells by activating PI3K/AKT and NF-κB signaling pathways. *Toxicol Res (Camb)* 2021; 10: 150–157.
23. Låg M, Øvrevik J, Refsnes M, et al. Potential role of polycyclic aromatic hydrocarbons in air pollution-induced non-malignant respiratory diseases. *Respir Res* 2020; 21: 299.
24. Kaden DA, Hites RA and Thilly WG. Mutagenicity of soot and associated polycyclic aromatic hydrocarbons to Salmonella typhimurium. *Cancer Res* 1979; 39: 4152–4159.
25. Shimada T, Takenaka S, Murayama N, et al. Oxidation of acenaphthene and acenaphthylene by human cytochrome P450 enzymes. *Chem Res Toxicol* 2015; 28: 268–278.
26. Näslund Andréasson S, Mahteme H, Sahlberg B, et al. Polycyclic aromatic hydrocarbons in electrocautery smoke during peritonectomy procedures. *J Environ Public Health* 2012; 2012: 929053–929056.
27. Claudio CV, Ribeiro RP, Martins JT, et al. Polycyclic aromatic hydrocarbons produced by electrocautery smoke and the use of personal protective equipment 1. *Rev Lat Am Enfermagem* 2017; 25: e2853.
28. Barrett WL and Garber SM. Surgical smoke: a review of the literature. Is this just a lot of hot air? *Surg Endosc* 2003; 17: 979–987.
29. Hill DS, O'Neill JK, Powell RJ, et al. Surgical smoke - a health hazard in the operating theatre: a study to quantify exposure and a survey of the use of smoke extractor systems in UK plastic surgery units. *J Plast Reconstr Aesthet Surg* 2012; 65: 911–916.
30. Tramontini CC, Galvão CM, Claudio CV, et al. [Composition of the electrocautery smoke: integrative literature review]. *Rev Esc Enferm Usp* 2016; 50: 148–157.
31. Breul S, Van Landuyt KL, Reichl FX, et al. Filtration efficiency of surgical and FFP3 masks against composite dust. *Eur J Oral Sci* 2020; 128: 233–240.
32. AORN. Guideline summary: surgical smoke safety. *Aorn J* 2017; 105: 498–500.
33. Ministry of Housing and Urban-Rural Development of the People's Republic of China. Technical specifications for the construction of clean surgical departments in hospitals, https://www.mohurd.gov.cn/gongkai/fdzdgknr/tzgg/201312/20131211_224896.html (2013, accessed 15 May 2024).
34. Mowbray NG, Ansell J, Horwood J, et al. Safe management of surgical smoke in the age of COVID-19. *Br J Surg* 2020; 107: 1406–1413.
35. Zheng MH, Boni L and Fingerhut A. Minimally invasive surgery and the novel coronavirus outbreak: lessons learned in China and Italy. *Ann Surg* 2020; 272: e5–e6.