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Comparison of the Effects of Surgical Smoke on the Air Quality and on the Physical Symptoms of Operating Room Staff

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Abstract

Background: Surgical smoke can be a hazard because e it contains toxic gases with carcinogenic effects that may threaten health. This study aims to determine the effect of surgical smoke containing toxic chemicals on indoor air quality and examine employees' physical symptoms in the operating room. **Method:** The study was conducted in the operating room between June 2020 and July 2020. In the study, 45 air samples were taken before, during, and after surgery using the active sampling method. Nineteen employees working in the operating room were asked about their physical complaints and their throat cultures were taken before and after surgery. These results were compared with those of the employees working in internal units. **Results:** The Total Volatile Organic Compounds value at the time of surgery was significantly higher ($p \leq 0.05$). Benzene concentrations remained constantly high ($p \leq 0.05$) throughout the surgery, exceeding the limit values. Other VOCs (Volatile Organic Compounds) were significantly higher during surgery and remained below the limit values ($p \leq 0.05$). When compared in terms of open and laparoscopic surgery, no difference between VOC concentrations was observed ($p \leq 0.05$). The physical symptoms of the surgical team increased during the operation, and they experienced more complaints of tearing, burning in the eyes, hair odor, nausea, and cough than those working in the internal units (e.g., internal medicine, dermatology; ($p \leq 0.05$). **Conclusions:** Surgical smoke was an important contaminant for indoor air quality in the operating room.

Keywords

indoor air quality, operating rooms, surgical smoke, surgery, employee safety

Introduction

Factors that cause indoor air pollution are stated to be particulate matter, combustion gases, bioaerosols, biological pollutants, Volatile Organic Compounds (VOC), and chemical pollutants such as radon. Improving air quality in operating rooms is dependent on air conditioning (temperature, humidity, ventilation) systems and the source, concentration, contact path, and duration of contact of chemicals (Demirarslan & Basak, 2018; Gioutsos et al., 2022).

One of the parameters influencing the indoor air quality in operating rooms is surgical smoke. Surgical smoke contains live and dead cellular materials, gaseous toxic compounds, bioaerosols, viruses, and bacteria. Surgical smoke during surgery occurs due to the use of electrical devices working at high temperatures such as laser, electrocautery, ultrasonic scalpel, bone saw, and drill used during excision, hemostasis, and dissection. Surgical smoke resulting from the use of electrosurgery and laser units causes the target cells to heat and break down, thereby spreading the aerosolized cell contents to the environment. Ninety-five percent of this smoke cloud that spreads into the air consists of water and 5% of it consists of burnt cell contents such as chemicals, lipids, blood pathogens, live viruses, and bacteria (Hill et al., 2012; Karjalainen et al., 2018). Cellular components and chemicals can be transported into the environment in the form of

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small parts, where they can affect the lungs as a consequence of respiration and can be harmful to the respiratory system (Okoshi et al., 2015; Ulmer, 2008). Surgical smoke has physical, biological, and chemical risks due to such harmful content.

Burnt cell content in surgical smoke can cause a wide range of serious health problems including irritation in the respiratory tract, infection, and genotoxicity for both patients and operating room workers (Hill et al., 2012; Ilce et al., 2017). Inhaling the particulate matter in surgical smoke can irritate the lungs and small particles can enter the circulation this way. The Environmental Protection Agency (EPA) reports that particulate matter which is of 10 μm or smaller can be inhaled, which in turn may cause long-term complications such as coronary artery disease, congestive heart failure, asthma, and chronic obstructive pulmonary disease (Limchantra et al., 2019).

Surgical smoke contains some viruses and bacteria and poses a biological risk. In the studies by Pierce et al. (2011) and Chodagiri (2013), bacteria such as *Staphylococcus aureus*, *Escherichia coli*, and *Neisseria* were detected in surgical smoke. Respiratory tract complaints are the ones that are mostly reported in the literature (Schultz, 2014; Usta, Aygin, Bozdemir, & Ucar, 2019). HPV (Human Papilloma Virüs), HIV (Human Immmunodeficiency Virus), tuberculosis, hepatitis B, and C viruses can spread into the air via surgical smoke and might cause infectious diseases in healthcare workers (Kwak et al., 2016; Mowbray et al., 2013). Still, there is no evidence to indicate whether COVID-19 is transmitted from surgical smoke (Antunes et al., 2021; Mowbray et al., 2013).

Surgical smoke has both chemical and toxic hazards because it contains toxic gases with cytotoxic and mutagenic effects that may threaten health (Lewin et al., 2011; OSHA, 2015). Surgical smoke has phenol, ethanol, chloroform, 1,2 dichloroethane, and styrene as well as the most well-known chemicals benzene, toluene, ethylbenzene, and xylenes (BTEX), various VOCs and Polycyclic Aromatic Hydrocarbons (PAH) such as naphthalene. Surgical smoke is reported to contain more than 100 toxic chemical compounds (Choi et al., 2018; Tramontini et al., 2016). Being one of the VOCs, benzene is recognized to be a carcinogenic chemical by the EPA and the International Agency for Research on Cancer (IARC). Other VOCs have many harmful effects on health although they are not classified as carcinogenic (EPA, 2021a; IARC, 2016). In a surgical smoke analysis using an animal model, the mutagenic potential generated by surgical smoke generation from 1 g of tissue is stated to be equal to that of 6 unfiltered cigarettes. The long-term effects of chronic surgical smoke exposure are not yet fully known (Hill et al., 2012). Such exposure is known to deteriorate indoor air quality like VOC and PAH, and symptoms of some diseases (e.g., asthma) may occur shortly after the exposure. As the symptoms caused by these contaminants are similar to those of the common cold and viral illness, it is often difficult to distinguish them from one another. Therefore, whether the symptoms disappear after moving away from the environment should be monitored (EPA, 2021b). This study was conducted to 1) determine the effect of surgical smoke on indoor air quality and 2) compare the effect of surgical smoke on physical symptoms and throat culture results between operating room workers and those who had never worked in the operating room.

Methods

The first stage of this is a repeated measures study. Air samples were collected to determine the effect of surgical smoke on the indoor air quality of the operating room. In the second stage, a case control study, data were collected to determine the physical symptoms caused by surgical smoke on the employees and compared with those of the control group.

Operating Room Indoor Air Analysis

Indoor air samples were collected in the general surgery operating room containing an operating table, an anaesthesia monitoring table, a ventilator, and an emergency cart. A HEPA filtered ventilation system was used. To be able to observe the changes due to surgical smoke, 45 air samples were collected for 3 weeks. Three air samples were collected per day as described in Table 1 and shown in Figure 1.

Studies on surgical smoke have been performed in laboratory environments with experimental animals or simulations, and this study has been conducted under real operating room conditions (Li et al., 2020; Sanderson, 2012; York & Autry, 2018). This study was conducted by collecting instant data in a real operating room environment, and each air sample was taken for 45 minutes. Between the dates the samples were collected, 30 surgeries were performed, including 13 cholecystectomies, 1 cecum and 2 pancreatic tumor excisions, 1 inguinal hernia, 2 total thyroidectomies, 4 parathyroidectomies, 1 gastric perforation, 3 for stomach cancer, 1 haemorrhoidectomy, 1 rectal tumor, and 1 esophagus tumor resection in the general surgery operating room.

Surgical smoke was actively collected by placing an air sampling pump (The SKC-Deluxe Model Air Sample Pump) at 45–60 cm to the respiratory distance of the operating room staff at a flow rate of 80 L per minute for 45 minutes after the incision started. Gas chromatography, an automatic direct measurement method for hydrocarbons, was used to analyse the samples. Thermal Desorption Unit Gas Chromatography- Mass spectroscopy (TD/GC-MS-Thermal Desorber Markes Unity-Thermo Scientific Trace, 1300-mass detector-Thermo Scientific ISQ QD) was conducted by using a capillary column (TG-624; 30.0 m × 0.25 mm × 1.4 μm). Samples were analysed in the Scientific Industrial and Technology Research and Application Centre by being preserved in sample containers in the cold chain.

Identifying Physical Symptoms Caused by Surgical Smoke on Workers

To determine the physical effects of surgical smoke, an information sheet called "Information Sheet for Healthcare

Table 1. Periods of Air Samples.

Period	Condition
Preoperative air samples	When the room is empty before the operations begin, for 45 minutes, 45–60 cm from the respiratory distance of the surgical team
Air samples at the time of surgery	Starting from the moment of the skin incision, when the surgical smoke was at its peak, for 45 minutes, 45–60 cm from the respiratory distance of the surgical team
Post-operative air samples	After the operating room was evacuated and the postoperative room cleaning was performed using Chlorex tablet (White King) surface disinfectant and, for 45 minutes, 45–60 cm from the respiratory distance of the surgical team

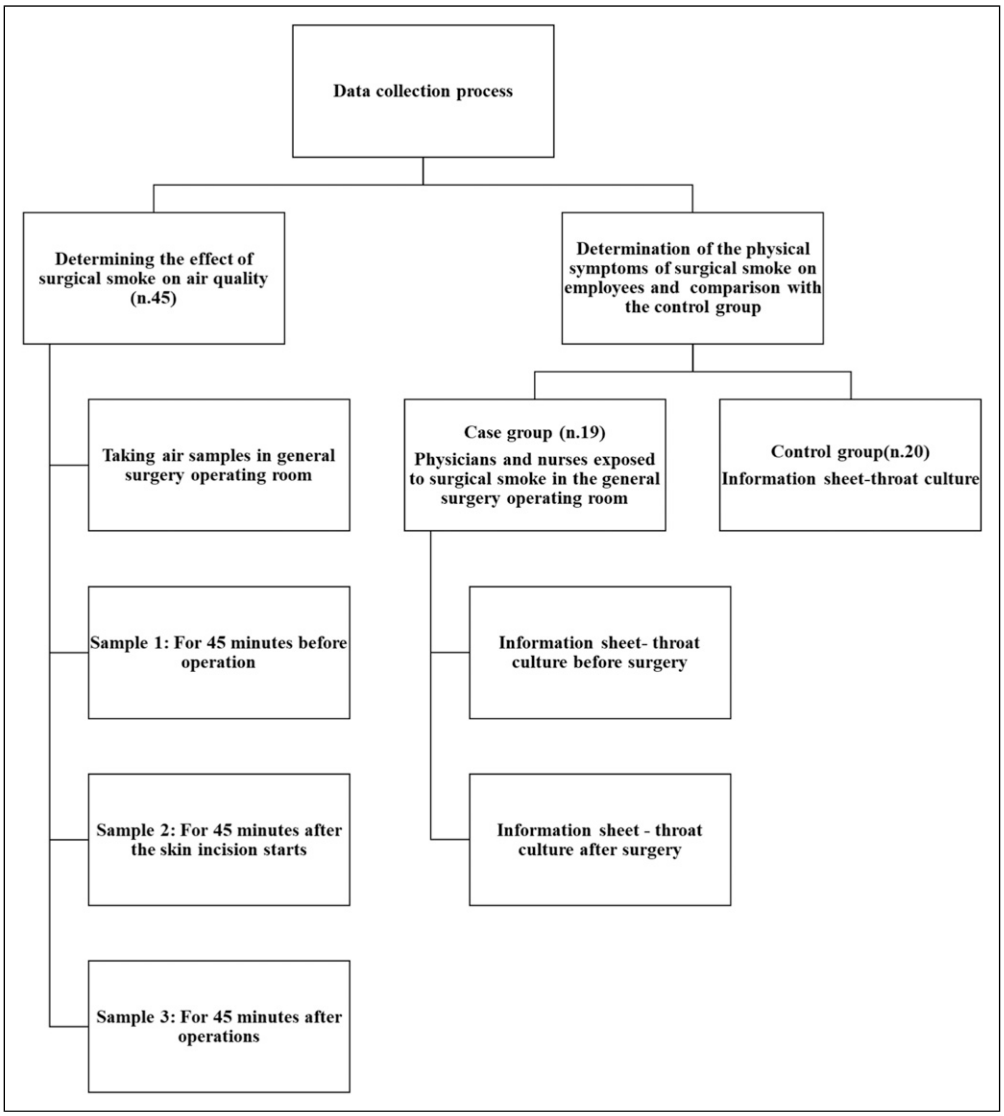

Figure 1. Project plan.

Professionals Exposed to Surgical Smoke" prepared by the researcher was used. This sheet consisted of 2 parts. In the first part includes descriptive characteristics and general physical problems experienced because of exposure to surgical smoke from employees before surgery. The second part contains information about acute physical problems (e.g., tearing, cough) experienced during surgery. Nineteen people in the operating room general surgery team including 3 lecturers, 6 general surgery assistants, 3 anesthesiologists, 3 anesthesia technicians, 3 nurses, and 1 assistant staff were included in the study.

Throat culture samples were taken from the employees to evaluate the indoor air quality in terms of biological pollutants. The first part of the information form was completed by the general surgery team before the first surgery of the day and throat cultures were taken before surgery. After the last operation of the day was over, data for the second part of the form were collected and second throat culture samples were taken.

To ensure the homogeneity of the selection of occupational groups, a random stratified sample selection was used for the control group. The control group consisted of 20 people, selected using the random sampling technique out of 120 people, who were working in the internal units of the hospital in which the study was conducted and who had not worked in the operating room. Twenty people, including 8 assistants, 4 nurses, 3 general practitioners, 4 technicians, and 1 assistant staff working in internal units took part in the study. The control group was asked about their physical complaints related to indoor air quality and their throat cultures were taken. All data were collected taking protective measures against COVID-19 by the researcher.

Data Analysis

The data were analysed using coding in a computer program and stated as percentage, mean ± standard deviation. Statistical evaluation was performed using a variety of tests including number, percentage Chi-square, t-test, ANOVA, and correlation tests to determine whether there was any difference between variables. $p \leq 0.05$; $p \leq 0.01$ and $p \leq 0.001$ were accepted as significant results in the evaluation of the findings. As for TVOC, the values were evaluated using the limit values specified in EPA 17 and Safe-Green Building standards, which is a particulate matter sampling method. WHO accepted TVOC limit values of 500 $\mu g/m^{-3}$ for indoor environments for EPA26. For an environment to be considered a Safe Green Building, the TVOC limit value is accepted as 200 $\mu g/m^3$ and the benzene limit value as 5 $\mu g/m^3$.

Trial Registration

Ethical approval no. 2019/122 was obtained from University Clinical Research Ethical Board. Necessary permissions were obtained from the hospital where the study was conducted. The clinical trial was registered using the name “Comparison of The Effects of Surgical Smoke on The Air Quality and on The Physical Symptoms of Operating Room Staff”. The Clinical Trial number is NCT04856995.

Results

Operating Room Indoor Air Quality Monitoring Results

General surgery operating room humidity was 63.6 (minimum: 52; maximum: 70), average temperature $\bar{x}$: 21.3 (minimum: 17; maximum: 23). When the pre-operative, operative, and post-operative temperature and humidity rates were compared, there was no statistically significant difference among them. The average cautery output power used in the operation was recorded as $\bar{x}$: 43.6 W (minimum: 35; maximum: 50). When cautery output powers used in open and closed surgeries were compared, these were used with similar power and there was no statistical difference between them ($p \leq 0.05$). The cleaning time of the room after the operations took an average of 9.1 ± 3.5 minutes (minimum: 5; maximum: 15).

In all samples taken in this study, the average benzene value was 5.07 $\mu g/m^3$. In all air samples taken, average concentration values of toluene, m, p-xylene, 1,2,4-trimethylbenzene, o-xylene, ethylbenzene, styrene and 4-isopropyltoluene (TVOC), naphthalene (PAH), tert-butylbenzene, sec-butylbenzene, benzene, n-propyl benzene, 1,3,5-trimethylbenzene, isopropyl benzene, and n-butylbenzene are shown in Figure 2.

The measured concentration averages of TVOCs during surgery 500.1 $\mu g/m^3$. This value is right at the limit of EPA standards and far above the Safe-Green Building standards (200 $\mu g/m^3$) (Figure 3). After the operation, the measured concentration average of TVOCs decreased to 242.6 $\mu g/m^3$ but exceeded the indoor environment TVOC limit value accepted for Safe-Green Building. The TVOC value at the time of surgery was significantly higher than the values measured before and after the operation ($p \leq 0.005$).

Benzene value was 3.9 $\mu g/m^3$ before surgery, 5.8 $\mu g/m^-$at the time of surgery, and 5.4 $\mu g/m^3$ postoperatively (Figure 4). Considering these results, the benzene value remained above the safe green building limit value during and after the operation. The difference among the measurements of benzene before, during, and after surgery was not statistically significant, and it remained high in the environment without significant change ($p = 0.06$). However, statistically significant differences between other VOCs were observed. VOC concentrations were higher than sample concentrations taken before, during, and after surgery (Table 2).

TVOC mean concentration was 328.99 during surgical procedures done in open surgery, and mean TVOC concentration was 248.3 in procedures during laparoscopic surgery. When the mean TVOC concentrations in open surgery and laparoscopic surgery were compared, no significant difference between them was observed ($p \geq 0.05$). When all the VOC concentrations seen in Figure 5 in the analysed air samples were compared according to the type of surgery (open or laparoscopic surgery), it was observed that there was no significant difference between them ($p \geq 0.05$).

The average duration of the operations performed in the general surgery operating room was 83.6 ± 38.5 minutes. The correlation value between the duration of the operation and the mean TVOC values was $r = -0.087$, and there was no significant correlation between them ($p \geq 0.05$).

Results of People Affected by Surgical Smoke

The average age of 19 people (general surgeons, assistants, anesthesiologists, nurses, and assistant staff) working in the

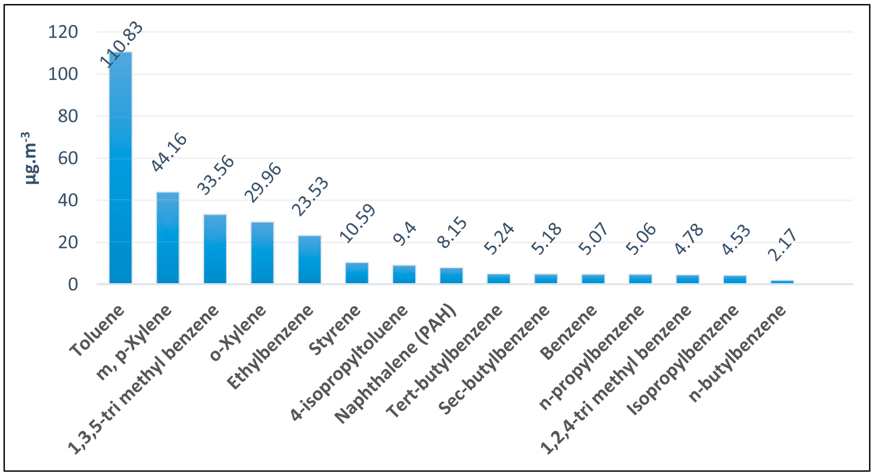

Figure 2. Average concentrations of VOC and PAH in air samples taken in the operating room.

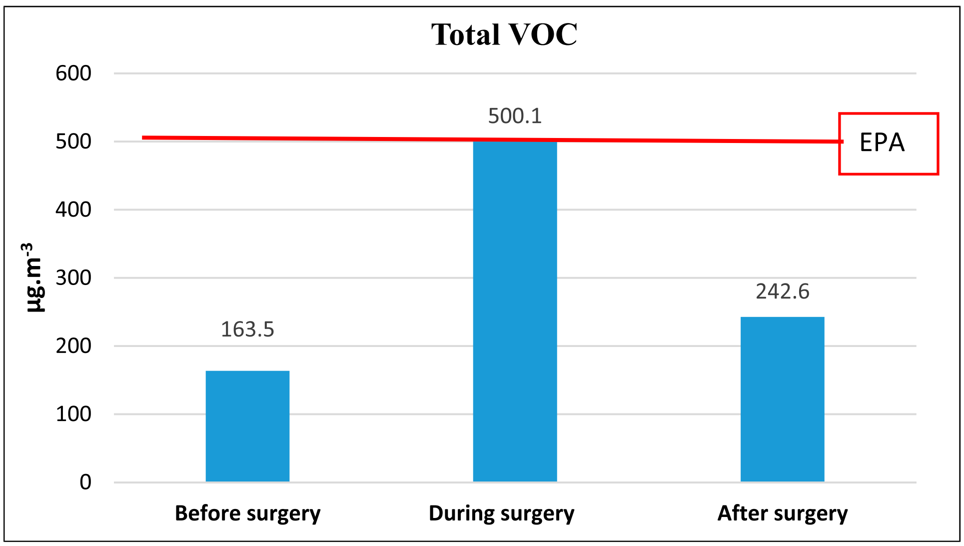

Figure 3. Comparison of the TVOC data from the operating room with EPA and safe green building criteria.

operating room general surgery room was 33.4 ± 8.8 years; 52.6% of them were female, the duration of working in the profession was 8.6 ± 9.0 years, and the duration of working in the operating room was 6.03 ± 7.8 years. In this study, 31.6% of the operation team were general surgery assistants, 15.8% were general surgeons, the same percentage were nurses, anaesthesiologists, and anesthesia technicians, and 5.2% were assistant personnel. It was seen that 84.2% of these employees did not smoke, and those who smoked in the remaining 15.8% group smoked fewer than 5 cigarettes a day. The average age of the employees working in the internal units was 30.6 ± 6.5, their working day was 7.6 ± 8.0 hours, and 71.8% of these employees were women. All participants reported that they had no chronic diseases and that 10.0% smoked 15 or more cigarettes a day.

Although 68.4% of the operating room team in the case group was disturbed by surgical smoke, they only used surgical masks; 78.9% did not receive any training on surgical smoke, and those who received information about surgical smoke did so due to their professional training and personal research. Of the surgical team, 94.7% stated that they understood the necessity of using a surgical mask, 36.8% knew they should use an aspiration catheter as a precaution against surgical smoke, 89.5% stated that the type of surgery (open or laparoscopic) will increase the negative effects of surgical smoke, and 78.9% stated that the negative effects of surgical smoke increase as surgery takes longer and added that they find the measures taken for surgical smoke insufficient.

The surgical team staff often suffered from tears, burning in the eyes, odor in the hair, nausea, cough, respiratory problems, throat burning, sneezing, dizziness, rhinitis, and drowsiness when they were exposed to surgical smoke. Similarly, they experienced burning in the eyes, odor in the hair, and nausea

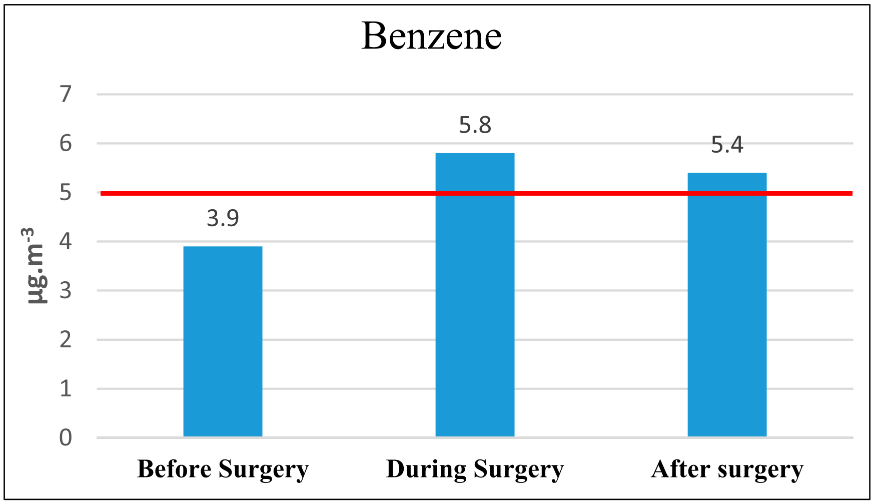

Figure 4. Comparison of Research Data with Maximum Criterion values Required for Benzene in Indoor Environment.

Table 2. Comparison of VOC and PAH Concentrations before, during and after Surgery (μg/m^3).

	Preoperative	During Operation	Postoperative	Statistical Analysis
Ion	Avg ± ss	Avg ± ss	Avg ± ss	(*p*)
Benzene	3.96 ± 2.4	5.82 ± 2.2	5.42 ± 1.9	0.06
Toluene	56.08 ± 59.5	149.48 ± 90.8	126.95 ± 173.3	0.001*
Ethylbenzene	11.41 ± 9.2	48.3 ± 53.3	10.79 ± 8.9	0.002*
m, p-Xylene	21.17 ± 18.9	88.15 ± 80.6	26.16 ± 20.4	0.001*
o-Xylene	13.47 ± 11.8	62.67 ± 60.3	13.81 ± 9.1	0.001*
Styrene	6.43 ± 6.9	18.04 ± 11.3	7.30 ± 5.6	0.005*
Isopropyl benzene	3.52 ± 7.4	7.58 ± 5.01	2.50 ± 1.5	0.0001*
n-propyl benzene	4.51 ± 9.1	7.74 ± 5.3	29.3 ± 1.6	0.001*
1,2,4-tri methyl benzene	3.28 ± 4.5	7.98 ± 4.5	3.07 ± 1.9	0.001*
Tert-butylbenzene	1.84 ± 1.4	9.97 ± 9.7	3.91 ± 2.7	0.003*
1,3,5-trimethyl benzene	17.7 ± 11.9	59.58 ± 4.1	23.36 ± 16.7	0.001*
Sec-butylbenzene	4.88 ± 9.9	7.59 ± 5.7	3.06 ± 1.7	0.003*
4-isopropyltoluene	6.89 ± 7.1	13.88 ± 6.8	7.44 ± 6.8	0.002*
n-butylbenzene	2.07 ± 4.7	3.13 ± 2.4	1.32 ± 0.8	0.001*
Total VOC	163.5 ± 120.1	500.15 ± 323.7	242.67 ± 271.6	0.001*
Naphthalene (PAH)	7.80 ± 16.8	11.81 ± 8.3	5.23 ± 3.1	0.001*

Note. *$p \leq 0.05$.

after leaving the surgery on the day of data collection. In addition, the complaints of tearing, burning in the eyes, odor in the hair, nausea, cough, respiratory problems, and burning in the throat increased significantly during the surgery ($p \leq 0.05$), as shown in Table 3.

No statistically significant difference was found between the throat culture samples taken from the employees in the general surgery operating room before and after the surgery in terms of Group A Streptococcal comparison. Upon evaluation of the throat cultures taken, there was no statistically significant difference between the staff working in the operating room and the healthcare professionals in other units in terms of the Group A Streptococcal scan.

Discussion

When the conducted literature review was scanned, VOCs are detected in the content of surgical smoke. Karjalainen et al. (2020) reported that in the air samples taken from the operating room, they detected only naphthalene among PAHs and benzene, toluene, ethylbenzene, and styrene among VOC. Van Gestel et al. (2020) reported that they took air samples in the operating room during a single shift (8 hours) for 5 days while performing surgical procedures and that they detected some VOCs (styrene, ethyl benzene, benzene, and toluene) and a PAH (naphthalene) in those samples (Van Gestel et al., 2020). Al Sahaf et al. (2007) reported that they collected samples

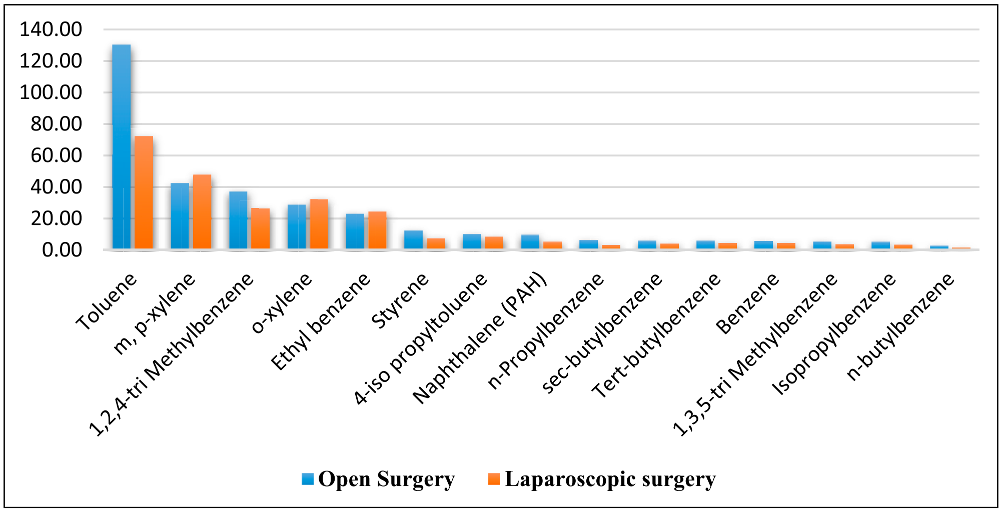

Figure 5. Comparison of VOC and PAH concentrations in the operating room in terms of open and laparoscopic surgical procedures.

Table 3. Comparison of the Problems Experienced by the Operating Room Team and Employees in İnternal Units.

Symptoms	Group A* (*n* = 19)		Group B** (*n* = 20)		Statistical Analysis (*p*)
	n	%	*n*	%	
Tearing	12	63.2	0	0.0	0.001
Burning in the eyes	11	57.9	2	10.0	0.002
Odour in the Hair	8	42.1	0	0.0	0.001
nausea	6	31.6	0	0.0	0.006
cough	6	31.6	1	0.0	0.031
respiratory problems	5	26.3	1	5.0	0.065
burning in the throat	5	26.3	2	10.0	0.184
Sneezing	4	21.1	5	25.0	0.770
Dizziness	3	15.8	1	5.0	0.267
Rhinitis	3	15.8	4	20.0	0.732
Drowsiness	3	15.8	2	10.0	0.589
Irritability	2	10.5	6	30.0	0.132
Conjunctivitis	2	10.5	1	5.0	0.517
Airway inflammation	2	10.5	1	5.0	0.517
Cramps	1	5.3	2	10.0	0.579
Dermatitis	0	0.0	1	5.0	0.323
Weakness	0	0.0	1	5.0	0.323

Note. * Group A: Employees in general surgery operating room team-case group; ** Group B: Employees in internal units - control group.

during tissue cauterization in 13 surgeries including verrus excision, pilonidal sinus excision, and abdominal surgery, and toluene, ethylbenzene, and xylenes were found in surgical smoke (Al Sahaf et al., 2007). When surgical smoke is formed, its concentration in the air increases even more and it becomes visible during surgery. For this reason, different from most studies in the literature, the air concentrations of the chemicals detected in the surgical smoke were determined by taking air samples at different times in the operating room in our study. In addition, whether these chemicals exceeded the limits to the extent that they could threaten the employees' health was examined. In this study, many VOCs (benzene, toluene, ethylbenzene, m, p-xylene, o-xylene, styrene, isopropyl benzene, n-propyl benzene, 1,2,4-trimethylbenzene, tert-butylbenzene, 1,3,5-trimethylbenzene, sec-butylbenzene, 4-isopropyltoluene, n-butylbenzene) and Naphthalene (PAH) were detected by indoor air analysis in the operating room. In our study, the air collection pump was placed in the closest place where the cautery was used within the breathing boundaries of the surgical team, and each air sample was taken from the same area before and after the operation for 45 minutes. High rates of VOCs and naphthalene (PAH), especially benzene, which exceed the limit numbers, were detected in the operating room environment. These chemical compounds were found to increase at the time of surgery when the surgical smoke was the highest. These data suggest that surgical smoke is a parameter that harms air quality.

In this study, benzene, whose presence in the operating room environment was detected by air analysis, is categorized to be in the class of carcinogenic chemicals. Moslem et al. (2020), Van Gestel et al. (2020), and Choi et al. (2014) reported that the benzene value in the air samples taken from different operating rooms is above the limit values (Choi et al., 2014; Moslem et al., 2020; Van Gestel et al., 2020). Similar to the findings in these studies, benzene was found in the air at the highest rate (5.82 ± 2.2) when surgical smoke was most intense in the indoor air analysis we performed in the operating room and was above the safe green building limit value during and after the surgery (5.42 ± 1.9). According to the results of cancer risk assessment studies conducted with benzene, it is reported to increase the risk of cancer (Moslem et al., 2020). She et al. (2017) stated that benzene also has a detrimental effect on human health, and that prolonged exposure to surgical smoke poses a great cancer risk. In et al.

(2015) examined living cells in surgical smoke by cauterizing cancer tissue and reported that the cancer cells found in surgical smoke were the same as the cancer cells cauterized, and when they applied these cancer cells in the surgical smoke to the back of rats, they observed them to grow. Another study conducted in the operating room revealed that the benzene value detected in air samples is low, yet long-term exposure to it may cause adverse effects on employees due to its carcinogenic effect (Van Gestel et al., 2020). The World Health Organization (WHO) reported a decrease in circulating lymphocytes in workers who were exposed to an average of 3.25 mg/m3 for 6 months (WHO, 1998). The average benzene concentration values in this study supported the previously published data that surgical smoke may be an occupational hazard to healthcare workers.

Although VOCs other than benzene are not classified as carcinogenic, they have many negative impacts on human health. In the study of Choi et al. (2014), cancer risk assessment of chemicals in surgical smoke revealed that toluene and xylenes are to be included in the group of non-carcinogenic chemicals which are still hazardous to health. She et al. (2017) report that surgical smoke generated in the laboratory using pork and pig liver does not exceed the threshold values of toluene, ethylbenzene, xylene, and naphthalene in terms of non-carcinogenic health risks associated with indoor air quality. In the same way, although toluene, ethylbenzene, xylene, and naphthalene were measured at higher values at the time of surgery than before and after surgery, their average values remained below the set limit value in this study. However, these chemical compounds, which increase indoors with the formation of surgical smoke, have harmful effects similar to those of cigarette smoke, although they do not exceed the limit value (Hill et al., 2012), and that long-term exposure poses a risk to healthcare workers and can cause many physical complaints (Ilce et al., 2017; Usta, Aygin, Bozdemir, & Uçar, 2019).

Dobrogowski et al. (2014) reported that they collected surgical smoke samples during laparoscopic surgery in the operating room and that benzene, ethylbenzene, and xylenes were recognized in surgical smoke based on the analysis of the obtained samples. Choi et al. (2017) measured VOCs in 3 different locations during laparoscopic surgery: in the abdominal cavity, near the surgical table, and the trocar hole. Results from the abdominal cavities revealed that benzene and toluene levels exceeded health guidelines and many VOCs were detected in surgical smoke. Measurements obtained on the operating table and trocar outlets showed that VOCs were found at lower rates compared to those found in abdominal cavities, yet the benzene concentration in the operating room approached a level that could threaten the health of the employees (Choi et al., 2017). Most of the operating room team who took part in this study stated that they thought there would be a considerable difference between the negative effects of surgical smoke due to the type of surgery (open-laparoscopic), and that there would be less surgical smoke during laparoscopic surgeries. However, when all VOC concentrations in analysed air samples were compared in terms of the type of surgery (open and laparoscopic surgery), it was seen that there was no significant difference between them ($p \geq 0.05$). Thus, surgical smoke during laparoscopic surgery caused as much air pollution as in open surgery.

Tseng et al. (2014) report no statistical relationship between operation time and airborne particulate and PAH concentrations. Similarly, no relationship was found between the mean values of TVOC and naphthalene (PAH) in our study. TVOC and PAH values remain stable without any rise as surgical operative duration gets longer. Therefore, our study supports that TVOC and PAH values can increase even in short-term surgical procedures.

Many previous studies have reported that surgical smoke affects employees adversely and causes them to have some physical complaints.(Aktas & Aksu, 2019; Ilce et al., 2017; King, 2018; Rodger, 2022). In this study, approximately 3/4 of the surgical team consisting of surgeons, assistants, anesthetists, nurses, and the auxiliary staff stated feeling uncomfortable with surgical smoke and reported similar physical complaints. This shows that all operating room workers experience the negative physical effects of surgical smoke. Unlike other studies, we compared physical complaints with those working in the internal units, and found that the complaints of tearing, burning in the eyes, odor in the hair, nausea, and cough were more common in the operating room team than in those working in other units ($p \leq 0.05$).

The standard surgical mask does not protect from surgical smoke due to the presence of small particles in surgical smoke. However, according to the studies aimed at surgical smoke, it is known that the operating room team mostly preferred the surgical mask (York & Autry, 2018). Although the assumption is that enhanced protective measures are being taken in terms of using personal protective equipment due to the COVID-19 pandemic, most of the operating room team traditionally preferred the surgical mask.

In the same way as viruses, some bacteria can also resist increasing tissue temperature and survive during the use of electrosurgery and laser devices. In studies on surgical smoke, it was reported that *Staphylococcus aureus*, *Escherichia coli*, and *Neisseria* bacterial strains reproduced during surgical procedures applying both lasers and electrosurgery units (OSHA, 2015). Considering this information, preoperative and postoperative throat cultures were obtained from the surgical team and examined in terms of Group A Beta Haemolytic Streptococci. There was no statistical difference in Group A Beta Haemolytic Streptococci throat cultures taken before and after surgery. Likewise, when the results were compared to the throat cultures of those working in internal units, there was no significant difference ($p \geq 0.05$).

Every study has limitations. The mains limitation of this study is that it was conducted in only one surgical suite in one hospital and the control groups was from the general surgery unit only.

Conclusion

The indoor air quality was negatively affected as the chemical compounds contained in the surgical smoke increased in the operating room environment. Surgical smoke increased undesirable physical symptoms among workers. We recommend the use of effective evacuation systems to remove surgical smoke from the operating room environment, the organization of training programs to eliminate the lack of knowledge among operating room employees, and the use of personal protective equipment, especially filtration masks. It is also important to establish standards, guidelines, laws, and regulations for protection from surgical smoke, and doing comparative studies with larger sample groups.

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Author Contribution

Soysal, GE contributed to conception and design contributed to analysis and interpretation drafted manuscript critically revised manuscript gave final approval agrees to be accountable for all aspects of work ensuring integrity and accuracy Ilce,A contributed to conception and design contributed to interpretation drafted manuscript critically revised manuscript gave final approval agrees to be accountable for all aspects of work ensuring integrity and accuracy Lakestani,S contributed to design contributed to analysis drafted manuscript critically revised manuscript gave final approval agrees to be accountable for all aspects of work ensuring integrity and accuracy Sit, M contributed to design contributed to acquisition drafted manuscript critically revised manuscript gave final approval agrees to be accountable for all aspects of work ensuring integrity and accuracy Avcioglu,F contributed to design contributed to analysis drafted manuscript critically revised manuscript gave final approval agrees to be accountable for all aspects of work ensuring integrity and accuracy

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