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Review Article

Surgical smoke: A hidden killer in the operating room

Yong-zhi Zhou [a, b], Chao-qun Wang [a, b], Meng-hua Zhou [b, c], Zhong-yu Li [a, b], Dong Chen [a, b], Ai-ling Lian [d, **], Yong Ma [a, b, *]

[a] Department of Minimal Invasive Hepatic Surgery of the First Affiliated Hospital of Harbin Medical University, Harbin, 150001, China
[b] Key Laboratory of Hepatosplenic Surgery, Ministry of Education, Harbin, 150001, China
[c] Department of Hepatic Surgery, The First Affliated Hospital of Harbin Medical University, Harbin, 150001, China
[d] Operating Room, The First Affiliated Hospital of Harbin Medical University, Harbin, 150001, China

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ABSTRACT

Surgical smoke is a byproduct of aerosols containing several components produced by energy equipment. The characteristics of surgical smoke components produced by different types of tissues or using different kinds of energy devices vary. For example, the average diameter of smoke particles produced by electrocautery is smaller, and the possibility of viable cells and pathogens in surgical smoke produced by an ultrasonic knife is higher. According to the characteristics of its composition, surgical smoke may be an important risk factor affecting the health and safety of operating room staff and patients. The use of surgical masks, suction devices and portable smoke evacuation systems can reduce this risk to some extent. However, most operating room staff members do not implement corresponding measures to protect themselves. In this paper, the characteristics of surgical smoke and the research progress in protective measures are briefly reviewed.

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1. Introduction

With the development of surgery, many energy devices, such as electric knives, ultrasonic scalpels and lasers, have been used in operations. Cutting by use of electric knives mainly relies on the thermal effect generated by the current passing through the tissue to dehydrate and solidify the tissue, while ultrasonic knives make the tissue cells collapse through the mechanical shock administered by the metal cutter head. Surgical smoke is a byproduct of aerosols produced by electrosurgical equipment, lasers and other energy equipment when cutting tissue or coagulating blood vessels. It contains several detrimental materials. This means that surgical smoke may have a harmful influence on the health. However, most operating room staff members have not attached importance to the potential danger. This article aims to introduce the specifics of surgical smoke and offer some methods to avoid its harmful effects.

2. The characteristics of surgical smoke

Although 95% of surgical smoke is water vapor, the constituents of the other 5% may cause health hazards. These include several kinds of components, such as inactive particles, chemicals, pathogens and active cells (Fig. 1).[1–3]

2.1. Inactive smoke particles in surgical smoke

The health hazard caused by inactive particles is closely related to their diameter. The particle matter depends on many factors in the surgery, such as the kind of energy equipment and tissues. The diameter of smoke particles produced by electrocautery is 0.07–0.42 μm, the diameter of smoke particles produced by lasers is 0.1–0.8 μm, and the diameter of smoke particles produced by ultrasonic scalpels is larger, 0.35–6.5 μm.[4] In addition, the diameter of smoke particles is related to the tissue. Karjalainen et al.[5] measured the particle size produced when using an electric knife to cut ten different tissues: skeletal muscle, liver, lung, bronchus, subcutaneous fat, renal pelvis, renal cortex, cerebral gray and white matter, and skin. According to the measurement results, these tissues can be divided into three groups: a high particulate matter (PM) group (liver), medium PM group (skeletal muscle, renal pelvis,

* Corresponding author.
** Corresponding author.
E-mail addresses: 776702705@qq.com (A.-l. Lian), mayong@ems.hrbmu.edu.cn (Y. Ma).

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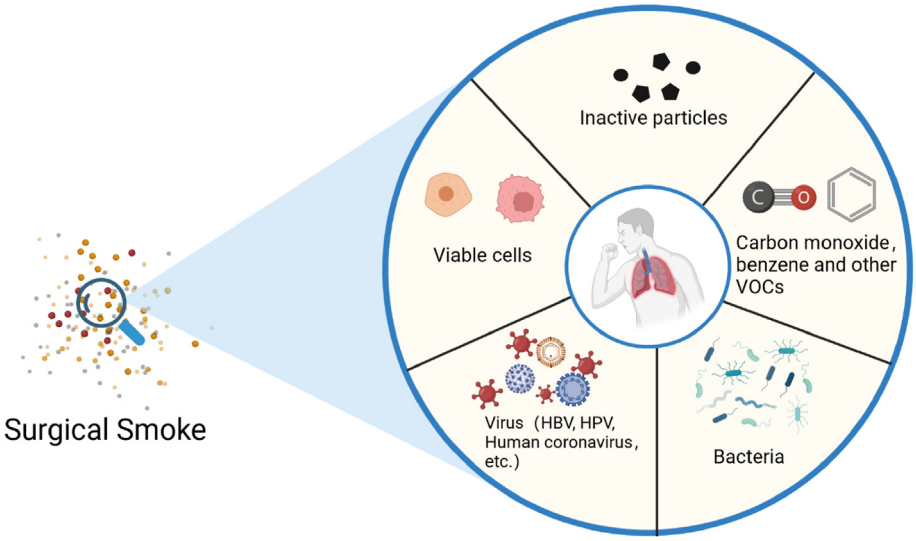


Fig. 1. The components of surgical smoke Abbreviations:VOCs, Volatile organic compounds; HBV, Hepatitis B virus; HPV, Human papillomavirus.

and renal cortex) and low PM group (lung, bronchus, subcutaneous fat, cerebral gray and white matter and skin). Why are we concerned about the diameter of surgical smoke particles? The particles will deposit at different positions based on their size and cause different levels of harm. For example, particles approximately 5 μm or larger are deposited on the wall of the nose, pharynx, trachea and bronchus. However, smoke particles smaller than 2 μm are deposited in bronchioles and alveoli, causing inflammation in the lungs.[1] Therefore, PM2.5 can be seen as a significant index for estimating the extent of harm.

2.2. Volatile organic compounds in surgical smoke

Dozens of volatile organic compounds (VOCs) have been identified in surgical smoke produced by energy devices, and these compounds include carbon monoxide (CO), benzene, toluene, ethylbenzene, xylene, styrene, formaldehyde, and acetaldehyde.[6–9] In addition, sevoflurane, a common anesthetic, has been found in surgical smoke. This means that the use of drugs can influence the composition of surgical smoke.[10,11] The composition of VOCs also depends on the type of energy device and tissue being ablated. For instance, abundant hydrocarbons, nitrifiers, fatty acids and phenols appear in surgical smoke generated by electrocautery. The smoke generated by laser tissue ablation has more benzene formaldehyde, acrolein, and polycyclic aromatic hydrocarbons.[12,13] The smoke produced by cauterizing epidermal tissue with a high-frequency electric knife contains higher levels of toluene, ethylbenzene and xylene, while the smoke produced by cauterizing adipose tissue contains lower levels of toluene and higher levels of aldehydes.[14] A study shows that the level of VOCs in surgical smoke generated by ultrasonic scalpels is lower than electrocautery in laparoscopic cholecystectomy.[15] Compared with muscle tissue, liver tissue can produce a higher concentration of furfural when burned by an electric knife.[16]

CO is generated because of incomplete combustion of tissue, and CO can be absorbed into blood through the skin, mucosa and respiratory tract. It is worth noting that the concentration of CO will increase due to the accumulation of gas in the abdominal cavity, and CO can be absorbed into the blood through the peritoneum. CO binds to hemoglobin to form carbonyl hemoglobin (HbCO), and its ability to bind to hemoglobin is much higher than that of oxygen. So can competitively bind hemoglobin with oxygen, thus inhibiting the binding of oxygen to hemoglobin.[17] This may cause hypoxia of various organs and tissues, leading to a series of uncomfortable symptoms, such as headache, dizziness, and fatigue. When the concentration of HbCO is beyond 50%, it may cause a severe harmful effect on health. Long-term exposure to a low concentration of CO can lead to dizziness and hypomnesia.[18] Consequently, we cannot ignore the potential harmful influence on the health caused by CO.

Acrylonitrile is another toxic volatile organic compound that attracts attention. It is colorless and can be absorbed through the skin and respiratory tract. The chemical properties of acrylonitrile are unstable, and cyanide ions (CN^-) can be precipitated.[19] The combination of CN^- with Fe^{3+} in the terminal enzyme of the respiratory chain (cytochrome oxidase aa3) inactivates the enzyme and blocks electron transfer and oxidative phosphorylation, thus inhibiting the utilization of intracellular oxygen. Short-term exposure to acrylonitrile can cause several syndromes, including eye irritation, sneezing and fatigue. Long-term exposure of skin to acrylonitrile can cause dermatitis. In addition, researchers have found that acrylonitrile may cause adverse reproductive effects in animal models.[20] Acrylonitrile and other VOCs, including benzene, cyclohexanone, formaldehyde, furfural, polyaromatic hydrocarbons, styrene, toluene and xylene, in surgical smoke have been identified as carcinogens.

2.3. Viable pathogens

2.3.1. Viruses and bacteria

One of the most concerning issues is whether disease can be spread through surgical smoke. Whether viable pathogens exist in surgical smoke is the crucial factor. Several kinds of viruses and bacteria have been detected in surgical smoke generated by different kinds of energy devices (Table 1). Kwak et al.[21] collected 11 surgical smoke samples during laparoscopic and robotic surgery. All of the patients chosen for sample collection were positive for hepatitis B surface antigen (HBsAg). The viral HBV DNA load in the blood ranged between undetectable and 1.7 × 108 IU/mL. As a result, HBV DNA was detected in 10 of 11 samples, even though the HBV DNA load in the blood was undetectable. However, the infectivity of HBV in surgical smoke is still unclear, and further experimental research is necessary.

Human papillomavirus (HPV) has been identified in surgical smoke generated from a CO_2 laser, electrocoagulation and loop

Table 1
Pathogens detected in surgical smoke.

Author	Year	Energy device	Pathogens
Ferenczy et al.[22]	1990	Carbon dioxide laser	Human papilloma virus
Michael et al.[36]	1991	Laser	Human Immunodeficiency proviral DNA
Schultz[38]	2015	Monopolar electrode	Serratia marcescens
Kwak et al.[21]	2016	Electrosurgical devices	Hepatitis B virus
Simon et al.[28]	2019	Potassium titanyl phosphate laser and Coblator	Murine Papillomavirus
Yokoe et al.[30]	2021	Electric scalpel and ultrasonic scalpel	Human coronavirus RNA
Zhu et al.[39]	2021	Electrocautery	Hafnia alvei
			Serratia liquefaciens
			Escherichia coli
			Aeromonas sobria
			Serratia marcescens
			Lactococcus garvieae
			Citrobter braakii
			Citrobacter freundii
			Raoultella planticola

electrosurgical excision procedures (LEEP) in vapor samples.[7,22,23] HPV DNA has also been detected on personal protective equipment, such as masks and medical gloves, during the treatment of laryngeal papillomavirus and genital warts.[22] Recently, a study found HPV-16, HPV-39, and HPV-53, considered three high-risk types of HPV, to be correlated with the respective HPV genotypes of the ablated patient lesion.[24] Zhou et al.[25] collected 134 swab samples of surgical smoke derived from LEEP and then detected HPV DNA by PCR. The results demonstrated a positive rate of HPV DNA of 29.9% in the samples. Meanwhile, the nasal epithelial cells of the two surgeons were positive for HPV DNA, and the genotypes were consistent with those in the corresponding surgical smoke. However, their nasal swabs became negative at the 3–6-month follow-up. Therefore, there is no precise evidence to prove that HPV in surgical smoke can cause infection in operating room staff. In a recent study, Hu et al.[26] aimed to investigate whether gynecologists who have performed electrosurgery, including LEEP, are at risk of HPV infection. They designed a questionnaire and collected 700 gynecologist nasal swab samples in 67 hospitals to explore the correlation between related factors, including electrical surgery and HPV infection, in the nasal samples of surgeons. The results showed that the infection rate of gynecologists who performed electrosurgery (8.96%, 42/469) or LEEP (10.11%, 36/356) was significantly higher than that of gynecologists who did not perform electrosurgery (1.73%, 4/231) or LEEP (2.91%, 10/344). Nonetheless, using a surgical mask can provide effective protection, significantly reducing the risk rate, and the protective effect of N95 masks is better than that of surgical masks. By the 24-month follow-up, 100% of gynecologists who were positive for HPV had become negative for HPV. For this reason, we can speculate that the infectivity of HPV in surgical smoke is transient. Two gynecologists who had over 20 years of experience performing physical ablation procedures, particularly CO_2 laser and LEEP, in HPV-associated lesions of the cervix and vulva were diagnosed with oropharyngeal squamous cell cancers. They did not have other relevant risk factors for HPV infection.[27] In another study, researchers treated nude mice with mouse papilloma virus (MmuPV1)) to establish MmuPV1 tail warts. Subsequently, smoke was collected when the warts were treated with potassium titanyl phosphate (KTP) laser ablation and Coblator treatment. Tail warts developed rapidly when the surgical smoke collected was used to inoculate mice. This indicated that MmuPV1 in surgical smoke had infectivity and pathogenicity.[28] In addition, the infectivity of bovine papillomavirus has also been demonstrated.[29] During the COVID-19 epidemic, there were concerns about whether the COVID-19 virus could be transmitted through surgical smoke. In an interesting in vitro experiment, human coronavirus RNA was detected in the collected surgical smoke.[30] Although there is no evidence to demonstrate that the COVID-19 virus can be transmitted through surgical smoke during surgical treatments, we cannot ignore this risk.[31–35] In an in vitro study, HIV proviral DNA and P24 protein were also found in surgical smoke generated from a CO2 laser.[36,37]

In addition to viruses, the existence of viable bacteria in surgical smoke has also been studied. Researchers applied electrode blades to porcine tissues that were treated with Serratia marcescens. Viable Serratia marcescens was not detected in surgical smoke when cutting coagulation or laser alone was used, but it was detected in surgical smoke from blended current cutting. At the same time, the interference of suction devices can play an important role in these results.[38] Zhu et al.[39] used swabs to collect smoke samples while porcine spinal tissues were electrocauterized. The results showed that 95% (19/20) of the smoke swabs were positive, with a total of 9 bacterial species identified. Using a surgical or N95 mask effectively reduced the “infection rate” of the swab.

2.3.2. Viable cells in surgical smoke

The possibility of diseases transmitted by surgical smoke is not limited to viruses and bacteria, and the existence of viable cells is another important factor. Cells have been detected in surgical smoke in laparoscopy and in vitro experiments.[40–42] To determine whether viable cells are present and evaluate their carcinogenicity, In et al.[43] performed a series of experiments in an operating theatre. They used three kinds of powered equipment, namely, bipolar electrocautery, radiofrequency ablation and ultrasonic scalpels, to manipulate cell lines and then detected viable cells in smoke samples collected by a transwell membrane. Viable cells were detected in smoke captured from a distance of 5 cm but only from the harmonic scalpel (100%, 25 of 25 experiments). The positive rate decreased with increasing distance (8%, 2 of 25 experiments). No viable cells were identified in surgical smoke from the electrosurgical unit or radiofrequency ablation device. A possible reason is that the temperature reached while using a harmonic scalpel is lower than that of the other techniques. Therefore, the integrity of the cell structure can be preserved to a greater extent. On this basis, the research team performed in vivo experiments. They collected smoke from the SCC7 mouse cancer cell line treated with ultrasonication, and the smoke sediment was injected on both sides of the lower back of 20 mice. After two weeks of observation, tumor growth was observed in 16 of 40 injection sites. Recent research shows that ultrasonic cutting of the liver has higher metabolic activity than electrosurgery of the liver. No viable cells were liberated when the bone was cut by bone saws and ultrasonic cutting.[44] Although no precise evidence can prove that viable cells in surgical smoke can cause transmission of disease, neoplasm

recurrence and tumor metastasis, this fact reminds us that viable cells in surgical smoke may be an adverse factor for patients and operating room staff. This confirms that a no-touch isolation technique is absolutely necessary in surgical operations.

3. The potential harmful effect caused by surgical smoke

3.1. Limiting the view of the operative field

Surgical smoke may have a potentially harmful influence on the health because of its various characteristics (Table 2). Surgical smoke can interfere with surgical procedures by limiting the view of the operative field, especially during laparoscopic surgery, because of the accumulation of surgical smoke in the abdominal cavity. In laparotomy, a special assistant is often needed to operate a suction device to remove surgical smoke and thereby avoid interference. In laparoscopic surgery, the surgeon often must stop operating to remove smoke to restore a clear field of view. These procedures may affect the progress of the operation and the safety of the surgical operation to some extent.

3.2. Causing discomfort to medical staff and increasing the incidence of disease

In a questionnaire survey, nearly half of the doctors and nurses who participated in the questionnaire reported a series of symptoms of discomfort, including headache, watering of the eyes, cough, sore throat, odors absorbed in the hair, nausea, drowsiness, dizziness, sneezing and rhinitis.[45]

There are a large number of particles smaller than 2.5 μm in surgical smoke.[46] Exposure to PM2.5 has obvious associations with asthma, chronic obstructive lung disease (COPD) and lung cancer through the activation of various signaling pathways.[47] PM2.5 can lead to the activation of oncogenes and inactivation of anti-oncogenes. Therefore, long-term inhalation of PM2.5 will increase the risk of lung cancer. The deposition of PM2.5 in the lower respiratory tract triggers an inflammatory response by activating Th2 cells and other inflammation-related cells and triggering oxidative stress.[48] Long-term exposure to PM2.5 is an independent risk factor for death from cardiovascular disease.[49] Each 10-μg increase in long-term exposure to PM2.5 can increase the mortality from ischemic heart disease by 16%.[50] It is worth noting that PM2.5 counts per hour and total counts of PM2.5 are significantly higher in open surgery than in laparoscopic surgery during the actual operation. Therefore, more attention should be given to protective measures against PM2.5 in open surgery.[51] Some researchers have noted that long-term exposure to surgical smoke may impair the reproductive capacity of female medical workers. Thus, surgical smoke has become a severely harmful occupational factor.[52] There are many kinds of VOCs in surgical smoke, and 9 toxic chemicals (acetylene, hydrogen, cyanide, 1,3-butadiene, benzene, toluene, furfural, styrene, ethylbenzene, and 1-decene) have been identified by using proton-transfer-reaction mass spectrometry in smoke.[53] The concentrations of these VOCs are several times higher than the allowed occupational exposure limit defined by the Swiss National Institute of Occupational Safety and Health (SUVA). Long-term exposure to carcinogenic chemicals may increase the risk of cancer. In an in vitro experiment, Sisler et al.[54] collected surgical smoke from human breast tissues being cut and coagulated by using an electrocautery surgical device and then treated human small airway epithelial cells (SAECs) and RAW 264.7 mouse macrophages with the collected smoke samples. The results showed approximately 25% cell death in SAECs and 40% cell death in RAW cells compared with the control group. After being treated with surgical smoke for 24 h, lactate dehydrogenase (LDH), which is a measurement of cellular membrane damage, was detected at significantly higher levels in the culture media. This means that surgical smoke can cause cellular membrane damage. The mutagenic potency of smoke on cells has been demonstrated, and some researchers have compared its harmful influence with that of cigarettes. DNA damage caused by surgical smoke is significantly higher than that caused by cigarette smoke.[55] It has been confirmed that the mutagenicity of surgical smoke generated by electrocauterizing 1 g of tissue is equivalent to 6 cigarettes.[56] Based on this, the mutagenicity of surgical smoke produced daily in a plastic operating room can be equivalent to 27–30 cigarettes.[57]

3.3. Increasing the risk of disease transmission

The presence of pathogens found in surgical smoke further increases the risk index of smoking. As described earlier, there have been reports of suspected cases of HPV causing infection among medical workers through surgical smoke. HBV is mainly transmitted through blood, sexual transmission and maternal-neonatal transmission, and it can lead to hepatitis, liver cirrhosis and even liver cancer. The discovery of HBV in surgical smoke provides a theoretical possibility for HBV to spread through the respiratory tract. Viable cells detected in surgical smoke may be one of the reasons for metastasis and recurrence of malignant tumors. Meanwhile, due to its rapid spread and strong ability to infect, COVID-19 has become a global problem to be solved. The COVID-19 pandemic has made people more concerned about the respiratory transmission of disease. Therefore, many medical staff are considering the role that surgical smoke might play in the COVID-19 epidemic and are aiming to evaluate the safety of surgical procedures in the background of the epidemic. Although no evidence shows that surgical smoke may contribute to the COVID-19 epidemic, we cannot exclude this potential danger.

4. Effective measures to avoid surgical smoke

4.1. Surgical masks, N95 masks and masks containing activated carbon

Wearing surgical masks is the most common protective measure used by medical workers in their daily work. Masks can provide protection to some extent by blocking droplets, the splashing of body fluid and large particles of dust. However, surgical masks cannot insulate medical staff from all of the harmful substances in surgical smoke and can only filter particles larger than 5 μm in

Table 2
The health hazards of surgical smoke.

Components	The harmful effects
Carbon monoxide (CO)	Long-term exposure to the low concentration of CO can lead to dizziness and hypomnesia.[18]
Acrylonitrile	Acrylonitrile may cause adverse reproductive effects.[20]
PM2.5	Increase the incidence of respiratory and cardiovascular diseases.[47,49]
Viable pathogens	Increase the possibility of disease transmission.[21,22,31–35]
Viable cells	Provide theoretical possibility of tumor metastasis.[45]

diameter.[58] Surgical masks cannot filter effectively when the particle diameter is less than 5 μm. There are many particles smaller than 5 μm, such as certain pathogens and VOCs. Therefore, surgical masks cannot provide adequate protection in such cases. N95 masks have been certified by the National Institute of Occupational Safety and Health of the United States; their filtering efficiency of particles with aerodynamic diameters of 0.075 μm ± 0.020 μm can reach more than 95%, while the average diameter of surgical smoke particles produced by electrocautery is 0.07 μm. Therefore, N95 masks can play a better role in the protection from surgical smoke. Using high-filtration masks such as N95 masks has been recommended.[59] Notably, the degree of adaptation between the mask and the face of medical staff will affect the protective effect of the mask. This is one of the advantages of N95 masks over surgical masks, as they can fit the face better. When using an N95 mask, medical staff should consciously check whether the mask is properly worn. If medical personnel can feel exhaled air coming out of the gap between the mask and the face, then the mask is not being worn properly. Health care workers would then need to adjust the mask immediately to ensure that it is airtight. Before medical staff enter the work environment, a device should be used to monitor particles in the indoor air as well as particles in the respirator. The suitability of wearing an N95 mask is assessed by the ratio between them. An experimental study demonstrated that activated carbon can effectively adsorb VOCs and reduce the concentration of VOCs in surgical smoke. Therefore, masks containing activated carbon filter elements can reduce the inhalation of VOCs and thereby play an effective protective role.[60,61]

4.2. Smoke evacuation devices

The use of smoke extraction equipment is another recommended protective measure.[62] In clinical work, surgical assistants often use aspirators to remove smoke. Only when aspirators are within 5 cm of the place where the smoke is generated and the gas flow rate reaches 31–46 m/min can they play an effective role in removing smoke.[63] Moreover, the angle of attraction is very important. The ideal attraction effect can be achieved by using aspirators at a 45° angle.[64] However, this behavior often affects the vision of the surgeon because of the lack of tacit cooperation. In addition, in laparoscopic surgery, the use of an aspirator to discharge smoke through the puncture hole will cause a rapid reduction in pneumoperitoneal pressure, which will lead to a reduction in the abdominal operating space and affect the surgical process. After laparoscopic surgery, when the puncture device is pulled out, the high concentration of surgical smoke accumulating in the abdominal cavity will be directly discharged into the operating room environment. This problem can be solved to a certain extent by using a disposable puncture device with a built-in filter, which can reduce the emission of benzene, toluene, butyral and other chemicals.[65] Most portable smoke evacuation devices are equipped with high-efficiency particulate air (HEPA) or ultralow particulate air (ULPA) filters. HEPA filters can remove 99.7% of particles ≥0.3 μm in diameter, while ULPA filters can remove at least 99.999% of particles ≥0.12 μm in diameter. This can effectively prevent particles in the smoke from being redischarged into the operating room air. Importantly, the smoke extraction efficiency is closely related to the angle of the smoke extraction equipment and the suction flow rate. A cutting angle of 45° and a volume flow rate of 10,500 m^3/h are the most favorable for smoke extraction efficiency.[66] Reasonable use of portable equipment can effectively remove smoke and has been recommended for clinical use.[67] However, such equipment has not been widely used in clinical work because of its noise. An experimental setting for a simultaneous smoke evacuation and CO_2 insufflation system using steady automatic pressure has been identified as useful in digestive endoscopy.[68] Therefore, we can try to use this device in laparoscopic surgery to both remove smoke and maintain pneumoperitoneal pressure. Many manufacturers integrate disposable smoke exhaust pipes and electrosurgical equipment. Such an integrated design enables the smoke exhaust equipment to maintain a relatively ideal distance from the electrosurgical equipment, and no special assistant is needed to hold the smoke exhaust equipment, which not only reduces unnecessary workload during the operation but is also conducive to the surgical process.[69] A new device, the circulating pneumoperitoneum machine, has been proposed for laparoscopic surgery to circulate and filter the gas in the abdominal cavity to effectively remove smoke and maintain a stable abdominal pressure, but this device has not been widely used.[70] Some surgical teams have designed simple devices to eliminate surgical smoke using underwater-seal evacuation and filters, which still need to be validated in clinical practice.[71,72] In addition to relying on the protective effects of various devices, the surgeon can also protect himself or herself by his or her own actions. In open surgery, it is often difficult to remove surgical smoke in a timely manner. Currently, the surgeon and his or her assistant can take actions such as turning their heads to avoid directly inhaling high concentrations of smoke, which can also reduce the harm to a certain extent.

4.3. Ventilation in the operating room

Inevitably, surgical smoke leaks into the operating room environment during surgery. Studies have shown that surgical fumes can leak through the gap between the instrument and the trocar during laparoscopic surgery.[73] Therefore, there is a low concentration of surgical smoke in the operating room environment. Good operating room ventilation is critical to avoiding the presence of smoke in the operating room air environment.[74,75] A positive air pressure room can push infectious particles away from the environment in the operating room.[76] In addition, an interesting study investigating the difference between different types of ventilation in the operating room showed that hybrid ventilation provides more effective protection than upward displacement ventilation. Hybrid ventilation results in a 10-50-fold reduction in colony-forming units (CFUs) in the protected area close to the patient's wound.[77] Therefore, using an appropriate ventilation system in the operating room is very important.

4.4. Enhancing the awareness of protection

The various protective measures described above are designed to minimize the potential harm that surgical smoke can cause to medical personnel. However, we found that most medical staff do not pay much attention to protection against surgical smoke in clinical work. A survey involving 4533 health care workers found that only 47% of the stuff involved in the laser surgery used local smoke extraction devices and the usage rate of devices in electrosurgery is lower (14%). Moreover, most of these medical workers had not used high-efficiency filtration masks such as N95 masks.[78] Therefore, it is essential for medical staff to engage in relevant training to improve their awareness of protection against surgical smoke.

5. Conclusion

The potential harm caused by surgical smoke has become a problem that cannot be ignored by operating room staff. Although some adverse effects, such as the possibility that pathogens and living cells in smoke may lead to the spread of disease, have not

Table 3
The comparison of surgical smoke generated by different surgical devices.

Surgical device	Particle diameter	Viable Cells	Virus	Bacteria	Organic chemicals
Electrosurgical scalpel	0.07 –0.42 μm[4]	Melanoma Cells[42]	Human coronavirus RNA[30] Human papillomavirus[25]	Serratia marcescens[38] Hafnia alvei Serratia liquefaciens Escherichia coli Aeromonas sobria Serratia marcescens Lactococcus garvieae Citrobter braakii Citrobacter freundii Raoultella planticola[39]	Acetylene, Hydrogen, Cyanide, 1,3-butadiene, Benzene, Toluene, Furfural, Styrene, Ethylbenzene, 1-decene,[9] Styrene, Heptene, Methylpropene[15]
Ultrasonic scalpels	0.1 –0.8 μm[4]	KB cells NCI –H292 cells SCC7 cells[43]	Human coronavirus RNA[30]		Benzene, Ethylbenzene, Styrene, Toluene, Heptene, Methylpropene[15]
Laser	0.35 –6.5 μm[4]		Human papillomavirus[22] Murine Papillomavirus[28] HIV proviral DNA[36]		Benzene, Formaldehyde, Acrolein, Polycyclic aromatic hydrocarbons[13]
LEEP			Human papillomavirus[25]		Benzene, Toluene, Xylene, Ethylbenzene, Styrene, Butyl acetate, Acrylonitrile, 1,2-, dichloroethane, Phenol, Chlorine, Cyanide, Hydrogen cyanide, Carbon monoxide[2]

been absolutely confirmed, it is necessary for medical personnel to be aware of the dangers of long-term exposure to surgical smoke and actively take corresponding protective measures. The safety awareness of operating room personnel is an important factor affecting the quality of protection. Only by strengthening the understanding of risk factors can operating room protective equipment be constantly improved and protective measures be strictly implemented. Protective measures should not be limited to existing protective equipment. For example, we can reduce the diffusion of surgical smoke by adsorbing it into the collection solution. Electrostatic precipitators (ESPs), devices usually used to control air pollution from smog-producing industrial facilities and power plants, can also be used in operating rooms. We should focus on developing new protective devices to remove surgical smoke more easily, quickly and effectively. Some low-cost and effective smoke evacuation devices have also been reported, which are constructed by common clinical materials. It means that the expenditure of developing new smoke evacuation devices will not be the main obstacle to the development of new devices.[72,79] In addition, the relevant safety authorities should develop detailed protection guidelines regarding surgical smoke as soon as possible.

We summarized the characteristics of components of surgical smoke produced by different surgical instruments in existing studies (Table 3). We can know that there is fewer VOCs in the surgical smoke produced by ultrasound scalpels than electrocautery. Therefore, choosing appropriate surgical devices in surgery may play a crucial role in reducing the harm of surgical smoke. However, studies on specific differences of surgical smoke generated by different surgical devices are still limited. It still needs to be further studied. In the future, the composition types of surgical smoke and the corresponding protection plans can hopefully be accurately predicted before surgery. In this way, we can maximize the safety and protect the health of operating room staff and patients.

Disclosure statement

The authors report there are no competing interests to declare.

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