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REVIEW ARTICLE

Health risks associated with exposure to surgical smoke for surgeons and operation room personnel

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Abstract Although surgical smoke contains potentially hazardous substances, such as cellular material, blood fragments, microorganisms, toxic gases and vapors, many operating rooms (ORs) do not provide protection from exposure to it. This article reviews the hazards of surgical smoke and the means of protecting OR personnel. Our objectives are to promote surgeons' acceptance to adopt measures to minimize the hazards. Depending on its components, surgical smoke can increase the risk of acute and chronic pulmonary conditions, cause acute headaches; irritation and soreness of the eyes, nose and throat; dermatitis and colic. Transmission of infectious disease may occur if bacterial or viral fragments present in the smoke are inhaled. The presence of carcinogens in surgical smoke and their mutagenic effects are also of concern. This review summarizes previously published reports and data regarding the toxic components of surgical smoke, the possible adverse effects on the health of operating room personnel and measures that can be used to minimize exposure to prevent respiratory problems. To reduce the hazards, surgical smoke should be removed by an evacuation system. Surgeons should assess the potential dangers of surgical smoke and encourage the use of evacuation devices to minimize potential health hazards to both themselves and other OR personnel.

Keywords Surgical smoke · Occupational health · Surgeon · Health problems · Operation room personnel

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Introduction

Although electrosurgical technology was developed by Harvey Cushing and William T. Bovie in 1926 [1], "surgical smoke" was not officially recognized as a significant hazard until the National Institute for Occupational Safety and Health (NIOSH) published and distributed a Health Hazard Evaluation Report in 1985 [2]. NIOSH, a department of the Centers for Disease Control and Prevention (CDC) within the US Department of Health and Human Services, stated in that report that there is a "potential hazard from exposure to smoke generated by electrocautery (electrosurgery) knives" [2]. This potential hazard has been a source of concern over recent years, and numerous studies [3–24] have attempted to determine the risks of surgical smoke, which is now also referred to as aerosols, cautery smoke, diathermy plumes, plumes or smoke plumes [25].

Surgeons and operating room (OR) personnel are routinely exposed to surgical smoke. Many research studies have confirmed that this smoke can contain potentially hazardous substances, including dead and living cellular material [8, 9], blood fragments [10], bacteria [18, 19], viruses [20, 23, 26, 27], toxic gases and vapors (e.g., benzene [2, 11], toluene [3, 11, 13, 14, 28], carbon monoxide [4, 15], acrylonitrile [11], methylpropene [28], acetaldehyde [12]) and lung-damaging particulates [29].

Surgical smoke control by local exhaust ventilation (LEV) has been recommended by professional

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organizations and government agencies in the United States, including the Association of periOperative Registered Nurses (AORN), the American National Standards Institute (ANSI), the Occupational Safety and Health Administration (OSHA), NIOSH and the CDC [30, 31]. However, according to a survey from the United States and Canada, many ORs still do not provide protection from exposure to surgical smoke, and the most common obstacle to providing such protection has been the surgeons' resistance or refusal to allow the use of LEV [32].

OSHA, an agency of the federal government charged with enforcing laws and regulations that protect employees in the United States, stated that an estimated 500,000 workers, including surgeons, nurses, anesthesiologists and surgical technologists, are exposed annually to laser or electrosurgical smoke. They further stated that surgical plumes can produce upper respiratory irritation, and have in vitro mutagenic potential. However, there are currently no specific OSHA standards for laser/electrosurgery plume hazards [33].

In the United Kingdom, the Health and Safety Executive, a national independent regulator that acts to reduce work-related death and serious injury in workplaces, states that diathermy emissions can contain numerous toxic gases, particles and vapors, the inhalation of which can adversely affect the surgeons' and theater staff's respiratory systems [34]. The Control of Substances Hazardous to Health Regulations (COHSS) require employers to carry out an assessment of the risks from hazardous substances and to always try to prevent exposure at the source [34]: under the COSHH guidelines, effective LEV is required to prevent exposure to diathermy emissions [35].

In Japan, the Japanese Association for Operative Medicine has stated that the smoke and mist generated during an electrosurgical procedure are potential hazards, and recommended that patients and perioperative staff should be prevented from inhaling it by removing it with an evacuation system [36]. However, there are no national regulations concerning this, and most surgeons and perioperative nurses in Japan are unaware of the potential hazards of surgical smoke.

The primary objective of this article is to demonstrate to surgeons that surgical smoke may present serious hazards to themselves and other OR personnel. The secondary objective is to discuss the possible means of avoiding or minimizing exposure to surgical smoke.

Potential health risks of surgical smoke

The composition of surgical smoke varies considerably, with the nature and size of the particles generated depending greatly on the type of procedure, energy used and power level employed. The adverse health effects to OR personnel vary depending on what the smoke contains. A list of potential risks to health is shown in Table 1 [37].

The effects of surgical smoke on the respiratory system are directly influenced by the size of the particles in it. Particles that are 5 μm or larger are deposited on the oropharyngeal walls, whereas aerosols between 2 and 5 μm are delivered to the airways and aerosols between 0.8 and 3.0 μm reach the pulmonary parenchyma [38] (Fig. 1).

According to Gates et al. [39], long-term OR employment and the resulting exposure to surgical smoke do not appear to increase the risk of lung cancer. Although Pukkala et al. [40] reported that male physicians had a low risk of lung cancer in five Nordic countries, the specific lung cancer risk of surgeons has not been reported.

Surgical smoke exposure may increase the risk of acute or chronic pulmonary conditions, such as asthma or pneumonia. With respect to acute respiratory symptoms, Navarro-Meza et al. [41] reported that in Mexico, many surgical residents develop lumps in their throats (58 %) and sore throats (22 %) as a result of exposure to electrocautery smoke. The plastic surgeons at Bryn Mawr Hospital in Pennsylvania noticed that several OR personnel were experiencing acute health effects, including upper respiratory and eye irritation, headache and nausea, during breast reduction procedures [2]. Ball et al. reported that the incidence of some respiratory problems, such as bronchitis, asthma, sinus infections and allergies in perioperative nurses was double that of the general population [42, 43]. In the United States, there was a significant association between OR nursing and severe persistent asthma, compared with administrative nursing [44]. Supporting these findings, Baggish et al. [29] examined the effects of long-term inhalation of carbon dioxide (CO_2) laser smoke on the

Table 1 The risks of surgical smoke (modified version of list of Alp et al. [37])

Respiratory system
Nasopharyngeal lesions, sneezing, throat irritation, acute and chronic inflammatory changes in respiratory tract (emphysema, asthma, chronic bronchitis)
Eyes
Eye irritation, lacrimation
Skin
Dermatitis
Gastrointestinal system
Nausea, vomiting, colic
Blood disorder
Anemia, leukemia
Infection
Human immunodeficiency virus, hepatitis, human papilloma virus [20, 23, 27, 36]
Others
Carcinoma, lightheadedness, hypoxia, dizziness, headache, weakness, anxiety

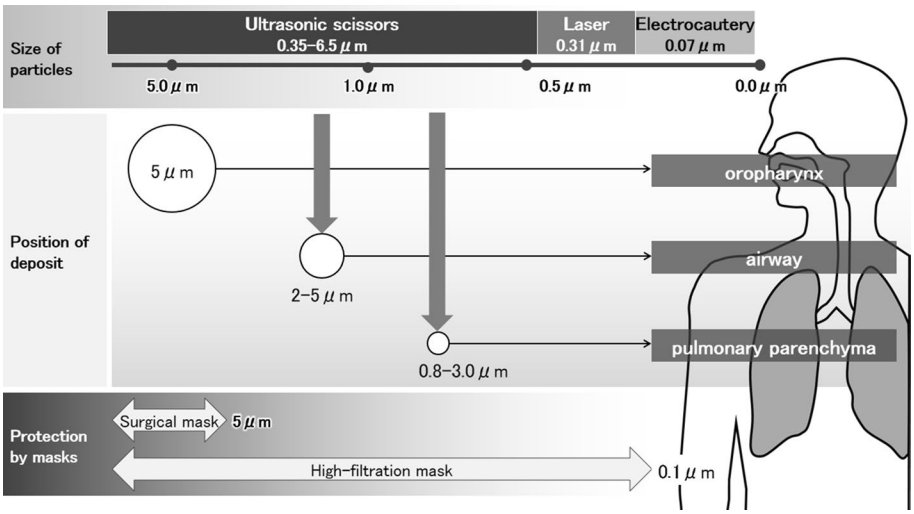

Fig. 1 The particle sizes, surgical devices, anatomical sites of deposition of particles and capacities of surgical and high-filtration masks to protect against particles

lungs of rats and showed pathological changes consistent with interstitial pneumonia, bronchiolitis and emphysema.

Components of surgical smoke

Surgical smoke is made up of 95 % water or steam and 5 % cellular debris in the form of particulate materials [31]. The amount and content of smoke generated varies widely from procedure to procedure. Factors that can affect the amount and content of smoke include the target tissue [11, 14], presence of particular bacteria [18, 19] or viruses [27, 45], the type of energy imparted (i.e., electrocautery vs. ultrasonic scissors [28], or bipolar vs. monopolar devices [46]), and the mode of cutting or coagulation [47].

The mean aerodynamic size of particles generated varies greatly depending on the device used. Electrocautery creates particles of the smallest aerodynamic size (0.07 μm) [47], whereas laser tissue ablation creates larger particles (0.31 μm) [48], and the largest particles are generated by ultrasonic scalpels (0.35–6.5 μm) [10] (Fig. 1). The smaller particles from any of these devices tend to travel greater distances from their point of production. In one study, the particles traveled up to 1 m from the impact site and were recovered from the upturned inner surface of the surgeon's eyeglasses after colposcopic laser treatment of genital condylomata [49]. In general, smaller particles are of greater concern from a chemical standpoint, whereas larger particles are of more concern from a biological standpoint [50]. The components of surgical smoke can be classified into chemical and biological components, as described in detail below.

Chemical composition

The chemical composition of surgical smoke has been well documented; a number of toxic chemical byproducts have been identified. According to a review by Pierce et al. [51], researchers have reported 150 chemical constituents of plumes. Electrothermal injuries and the burning of proteins and lipids produce a noxious odor that is noticeable to personnel in the OR. As noted above, in addition to possible long-term effects, these chemicals may cause acute headaches and irritation and soreness of the eyes, nose and throat [31, 37].

Of the many chemical compounds that may be present in surgical smoke, the toxic substances of concern, and the risk category, along with the International Agency for Research on Cancer (IARC) [52] and workplace exposure limits (WELs) by COHSS [53] are shown in Table 2. WELs are British occupational limits, and are set to help protect the health of workers. Two time periods are used to set limits: long-term (8 h) exposure limits (LTELs) and short-term (15 min) exposure limit (STELs) [53].

Short-term exposure to acrylonitrile can cause eye irritation, nausea, vomiting, headache, sneezing, weakness and lightheadedness. Long-term exposure causes cancer in laboratory animals and has been associated with higher incidences of cancer in humans. Repeated or prolonged exposure of the skin to acrylonitrile may produce irritation and dermatitis [37]. OSHA has set the upper limit of ambient exposure to this substance at 2 ppm. Exposure levels of OR personnel have been demonstrated to be 1.6 ± 1.0 ppm, just under this established limit [54].

Benzene causes irritation in the eyes, nose and respiratory tract, as well as headaches, dizziness and nausea. Even at relatively low concentrations, long-term exposure may result in various blood disorders, from anemia to leukemia. Many of the blood disorders associated with benzene exposure can be asymptomatic [37]. OSHA has set permissible exposure limits for the inhalation of benzene, because this substance is a documented cause of leukemia [31]. High concentrations of benzene (exceeding the specified limits)

Table 2 The chemicals in surgical smoke and their adverse effects

Acetaldehyde [12, 31, 64]	Eye, skin and respiratory irritant. Clinical exposure to vapors can also induce erythema, coughing, pulmonary edema and narcosis. May be teratogenic. Irritation can be expected after exposure to 50 ppm for 15 min. May facilitate uptake of other atmospheric contaminants by bronchial epithelium [31]. Acetaldehyde has been classified as a Group-2B (possibly carcinogenic to humans) carcinogen by the IARC [52]. LTEL: 20 ppm; STEL: 50 ppm [53]
Acetylene [25, 50]	Headache, dizziness, reduced visual acuity, poor judgment, memory and coordination; weakness, unconsciousness; rapid pulse and respiration, cyanosis [70]
Acrolein [31, 64]	Eye, skin and upper respiratory tract irritant. May increase blood clotting time and cause liver and kidney damage [31]. Acrolein has been classified as a Group-3 (Not classifiable as to its carcinogenicity to humans) carcinogen by the IARC [52]. LTEL: 0.1 ppm; STEL: 0.3 ppm [53]
Acetonitrile [25, 31, 50]	Nose irritant, throat asphyxiant. Has caused liver and kidney damage in animal models [31]. LTEL: 40 ppm; STEL: 60 ppm [53]
Acrylonitrile [11, 15, 25, 37, 50]	Colorless volatile liquid that will liberate cyanide and is easily absorbed through the skin and lungs [25]. Short-term exposure can cause eye irritation, nausea, vomiting, headache, sneezing, weakness and lightheadedness, and long-term exposure may cause cancer [37]. Acrylonitrile has been classified as a Group-2B (possibly carcinogenic to humans) carcinogen by the IARC [52]. LTEL: 2 ppm [53]
Benzene [24, 25, 31, 37, 50, 55, 64]	Headache, weakness, appetite loss and fatigue. May cause bone marrow damage, injury to blood-forming tissue from chronic low-level exposure. The threshold value limit in parts per million inhaled intermittently over one year may alter the nutritional status and gross metabolism [31]. Benzene has been classified as a Group-1 (Carcinogenic to humans) carcinogen by the IARC [52]. LTEL: 1 ppm [53]
Carbon monoxide [4, 15, 50]	Headache, fatigue, nausea, vomiting, cardiac dysrhythmias, myocardial ischemia, lactic acidosis, syncope, convulsion and coma, depending on the degree of exposure and susceptibility of the individual [50]. LTEL: 30 ppm; STEL: 200 ppm [53]
Cyclohexanone [13]	A potent respiratory irritant. Classified as a carcinogen for humans and suspected neurotoxicant. Major component released during abdominal surgery [13]. Cyclohexanone has been classified as a Group-3 (Not classifiable as to its carcinogenicity to humans) carcinogen by the IARC [52]. LTEL: 10 ppm; STEL: 20 ppm [53]
Decane [13, 24]	Eye, skin and respiratory tract irritation; headache; dizziness, stupor, incoordination; loss of appetite, nausea; dermatitis [70]
Formaldehyde [31, 50, 64]	Eye, nose, throat and respiratory system irritant. Exposure may cause cough and bronchospasm. Sensitizer. Shown to cause nasal tumors in rats [31]. Formaldehyde has been classified as a Group-1 (Carcinogenic to humans) carcinogen by the IARC [52]. LTEL: 2 ppm; STEL: 2 ppm [53]
Furfural [3, 12, 25]	Irritation of eyes, skin and upper respiratory irritation; headache; sore throat, cough, shortness of breath, vomiting [70]. Furfural has been classified as a Group-3 (Not classifiable as to its carcinogenicity to humans) carcinogen by the IARC [52]. LTEL: 2 ppm; STEL: 5 ppm [53]
Hydrogen cyanide [37, 50]	Hydrogen cyanide is a toxic colorless gas that is easily absorbed by the lungs, gastrointestinal tract and skin. It combines with ferric iron in cytochrome oxidase, thereby inhibiting cellular oxygen utilization [50]. STEL: 10 ppm [53]
Polyaromatic hydrocarbons (e.g., naphthalene) [31, 54, 64]	Absorbed via the respiratory tract. Ocular and respiratory irritant. Wide range of sensitivity. Effects noted at very low doses. Exposure likely occurs via particle inhalation [31]. Naphthalene has been classified as a Group-2B (possibly carcinogenic to humans) carcinogen by the IARC [52]
Styrene [24, 25, 31, 50, 64]	Respiratory irritant. Short-term vapor exposure in animal studies found damage to the lining of the nose [31]. Styrene has been classified as a Group-2B (possibly carcinogenic to humans) carcinogen by the IARC [52]. LTEL: 100 ppm; STEL: 250 ppm [53]
Toluene [3, 14, 24, 25, 31, 50, 64]	Well absorbed via inhalation. Vapors irritate the eyes and respiratory tract. Extensive documentation of effects in animal models, many related to central nervous system functions High levels associated with teratogenesis [31]. Toluene has been classified as a Group-3 (Not classifiable as to its carcinogenicity to humans) carcinogen by the IARC [52]. LTEL: 50 ppm; STEL: 100 ppm [53]
Xylene [24, 31, 50, 64]	Well absorbed via the respiratory tract. Respiratory tract irritation begins at 200 ppm. Chronic exposure is associated with reversible changes in red and white blood cell counts and increases in platelet counts [31]. Xylene has been classified as a Group-3 (Not classifiable as to its carcinogenicity to humans) carcinogen by the IARC [52]. LTEL: 50 ppm; STEL: 100 ppm [53]

have reportedly been detected near the diathermy electrode during colorectal surgery [55].

Hydrogen cyanide is a colorless toxic gas that may cause headache, weakness, throat irritation, vomiting, dyspnea, lacrimation, colic and nervousness after absorption through the skin and lungs [37]. Polycyclic aromatic hydrocarbons, the main byproducts of incomplete combustion, are ubiquitous environmental pollutants [56]. Both gaseous and particle-bound polycyclic aromatic hydrocarbons enter the human lung to a certain extent during respiration, inducing toxicity and carcinogenic effects [56]. One of these polycyclic aromatic hydrocarbons, naphthalene, causes ocular and respiratory irritation at very low doses [31].

Toluene is well absorbed via inhalation and irritates the eyes and respiratory tract. Its effects in animal models have been extensively documented, many being related to central nervous system functions and high levels being associated with teratogenesis [31]. Lin et al. [14] reported that the toluene produced during a single breast surgery was 2252 μg. Except for cigarette smokers and those who work with toluene-containing products, members of the US public are generally exposed to about 300 μg daily [57].

One study has demonstrated that electrosurgical smoke reduces the clonogenicity of MCF-7 human breast carcinoma cells in a dose-dependent manner; the authors concluded that electrosurgical smoke is cytotoxic to cultured cell lines [5]. Surgical smoke is also mutagenic, its mutagenic potency being at least equivalent to that of cigarette smoke [17]. The mutagenicity created by thermal destruction of 1 g of tissue is equivalent to that of three to six cigarettes [17], and the mutagenic potential may vary among people due to differences in susceptibility [16]. Fitzgerald et al. [28] reported that the electrocautery plume in the setting of live laparoscopic intraabdominal surgery had significantly lower concentrations of volatile organic hydrocarbons than cigarette smoke, but the concentrations of toluene and methyl propene were at equivalent levels to those in cigarette smoke.

Biological composition

Viable bacteria and viruses

The viability of the particulate matter in surgical smoke that may be inhaled has yet to be demonstrated conclusively. Five bacterial cultures grown on specimens collected from plume smoke during laser resurfacing in 13 patients grew coagulase-negative *Staphylococcus*. One of these five positive cultures also grew *Corynebacterium* and another *Neisseria* [19].

Travella et al. [23] have reported that the oral polio vaccine virus can survive excimer laser ablation. In one study, proviral HIV DNA was recovered from the suction tubing used to remove a CO_2 laser plume [27], and in another, strands of human papillomavirus DNA were isolated from a CO_2 laser plume during the treatment of plantar warts [58]. CO_2 laser surgeons have a higher risk of acquiring nasopharyngeal lesions, especially when they have been treating genital warts [22]. A case report linked the laryngeal papillomatosis in a surgeon who used neodymium-doped yttrium aluminum garnet (Nd:YAG) laser to virus particles in the laser plume from one of his patients [45].

Viable malignant cells

In one study in which pellets of B16-F0 mouse melanoma cells were cauterized and the electrocautery plume was collected in culture medium, intact melanoma cells were identified in the culture media [8]. The authors of that study concluded that viable cancer cells can be disseminated in the abdominal cavity and that this can lead to port-site metastasis in laparoscopic surgery. However, others have concluded that malignant cells only aerosolize during laparoscopy in the presence of carcinomatosis, and that it is unlikely that tumor aerosolization contributes significantly to port-site metastasis [59, 60].

Smoke from various tissues

It has been reported that fatty tissue generates 17–23 times more particles than lean tissue when the ball tip of an ultrasonic device is used, and 11–20 times more particles when a hook tip is used [10]. The authors of those studies speculated that this difference is probably attributable to the water content being higher in fatty tissue than in muscle. Zhao et al. [11] reported that 39 and 16 types of gases are generated during transurethral resection of the bladder and prostate, respectively, and that there are differences in the types of gases between benign hypertrophic prostate and malignant bladder tumor tissues. Thus, the amount and type of smoke compounds can vary with different surgical sites or tissues.

Smoke generated by various surgical devices

Electrocautery

Numerous chemicals, some of which are hazardous and present in greater than negligible quantities, have been found in surgical smoke generated by electrocautery. The most abundant chemicals in electrocautery smoke are hydrocarbons, nitriles, fatty acids and phenols [50]. Although electrocautery is potentially less hazardous than laser smoke as a route of disease transmission, human papilloma virus DNA has been identified in the smoke from warts treated with electrocoagulation [61].

Ultrasonic scissors

On the whole, although many studies have been carried out on the surgical smoke generated by electrocautery [3–5, 7, 8, 11, 14, 16, 24] and lasers [17–23], far fewer have focused on that generated by ultrasonic scissors, and no agreement yet exists about such smoke's exact composition.

The ultrasonic scissors produce a vapor rather than smoke [62]. Because the process involves low-temperature vaporization, tissues do not desiccate from the loss of moisture, and they do not burn [63]. High concentrations of cellular debris (more than 1×10^7 particles/mL) have been found in the plumes generated by ultrasonic scalpels; approximately a quarter of the concentration found in plumes generated by dissection of a similar amount of tissue with electrocautery [10].

One study indicated that the particles created by the ultrasonic scissors are composed of tissue, blood and blood byproducts [10]. However, another study reported that, although large numbers of cellular particles are released after ablation with ultrasonic scissors, very few were morphologically intact, and there were no viable cells [9].

Lasers

The chemicals that have been found in the plumes generated by laser tissue ablation with either CO_2 or Nd:YAG lasers include benzene, formaldehyde, acrolein and PAH [64]. Furthermore, viable particles have been found in these plumes, as described above. In general, the smoke generated by laser tissue ablation has more infectious potential than that generated by electrocautery [61].

Exposure to surgical smoke in the OR

It is commonly believed that the scrubbed members of a surgical team are at greater risk from inhaling smoke than those further away. In fact, surgeons working 20–40 cm from the point of smoke generation are exposed to the highest concentrations of plumes [7]. However, nurses and other OR personnel, along with anesthesia providers, are constantly exposed to the hazards of surgical smoke; the exposure of surgeons is often much less because they may operate only a few times a week [30].

Typically, within 5 min of the beginning of an electrosurgical procedure, the particulate matter in the immediate area increases from a baseline of approximately 60,000 particles per cubic foot to one million particles per cubic foot. A typical OR airflow recirculating system takes approximately 20 min to return particle concentrations to normal after the completion of a surgical procedure [65]. An investigation by Bruske-Hohlfeld et al. [6] showed that, during electro-cauterization and argon plasma tissue coagulation, surgeons and close assisting OR personnel have very high exposure to ultrafine particles (>100,000 cm^{-3}), and are briefly exposed to very high concentrations of ultrafine particles, followed by longer exposure to lower concentrations of such particles.

Countermeasures for reducing surgical smoke

To ensure the safety of OR personnel, approaches could include minimizing the production of surgical smoke, increasing the efficacy of its evacuation and preventing its inhalation using effective masks. In addition, given that a burning clot with laparoscopic coagulating shears reportedly generates more surgical smoke than when the clot is not burnt, the judicious use of devices can reduce the amount of smoke produced [12].

Combination of general room ventilation and LEV in the OR

All ORs have ventilation systems to capture and extract bacteria and dust particles. In the United States, a minimum of 15 air exchanges through general air circulation is required in ORs, and all rooms should be maintained at positive pressures [31]. The recommendations of the Japanese Association for Operative Medicine are similar [66].

However, this alone does not prevent the emission of smoke into the OR or the exposure of staff to it: LEV is required to achieve this [35]. The most important precautionary measure is the use of adequate evacuation systems. Ott et al. [10] showed that, although air concentrations of blood and tissue particles increase during the use of ultrasonic energy devices, local exhaust evacuation methods diminish these concentrations. Studies have shown that the inlet nozzle is 1 cm from the treatment site [20, 29].

Strategies according to surgical approach (open or laparoscopic)

Open surgery

Several smoke evacuation systems for open surgery are available and have been evaluated [31, 67]. Examples of devices that are used to capture plumes include smoke evacuation suction wands, electrosurgical unit pencils, and the newest capture device, which is based on cell foam technology, has an open cell foam core sandwiched between layers of nonporous plastic to retain smoke within the device and prevent a loss of suction power [67]. These capture devices are connected to desktop suction pumps called LEV, with ultra-low particulate air filters [67]. Newly constructed ORs can install a central smoke evacuation system [31]. Such central evacuation systems remove

the smoke directly to a remote site without using filters [67]. Although the nanoparticle capture of such central units is near complete (98–100 %), this system is slightly noisier than a desktop system [67].

Edwards et al. [32] reported that the most commonly encountered obstacle is the surgeons' resistance or refusal to allow LEV, and surgical team members complaining of the negative impact of noisy and bulky (or large) devices. The noise of the smoke evacuation unit is reportedly 55–60 dB maximum [67].

Laparoscopic surgery

It is possible to evacuate and filter surgical smoke through special laparoscopic devices. Automatic smoke evacuation provides a better view and reduces the risk of exposure to harmful compounds [12]. The smoke released from a cannula is generally more concentrated than that generated by open surgery, because in the former situation, the smoke accumulates and is then released all at once in a relatively high-velocity jet in a particular direction. Surgeons or other OR personnel at whom such jets are pointing can be exposed to high concentrations of smoke [50]. To prevent this, surgeons must not release cannulas; in addition, surgical smoke should be evacuated and filtered during laparoscopic procedures. It is possible to reduce smoke production using devices that produce less smoke, such as bipolar electrosurgical units or tissue fusion systems [46]. When the pneumoperitoneum is released at the end of laparoscopic procedures, to prevent the spewing of abdominal contents into the faces of surgical team members, surgical smoke should be evacuated and filtered thorough evacuation system [31].

Limitations of surgical masks and respirators

Surgical masks are the most commonly used type of protective facemask in perioperative and other hospital settings. Although surgical masks provide a barrier to splashes and droplets impacting on the wearer's nose, mouth and respiratory tract, they do not provide protection against airborne (aerosol) particles [68]: most surgical masks are designed to filter particles that are $\geq$5 μm [30]. Masks worn loosely or for too long are less effective; they should be worn snugly and changed often [30].

Respirators that provide respiratory protection for individuals are available. The European standard for filtering face masks lists three classes of filtering face pieces (FFP): FFP1, FFP2 (approximately equivalent to N95) and FFP3 [68]. High-filtration masks have been designed to filter particles as small as 0.1 μm [30]. Although wearing such masks affords some respiratory protection, viral particles can be much smaller than 0.1 μm [69]. Because high-filtration masks hinder normal breathing, they are not very popular among OR personnel. In a study throughout North America in 2010, the AORN reported that only 1–2 % of OR personnel used respiratory protection with N95 or other NIOSH-approved respirators during various types of electrosurgery, the exceptions being condyloma surgery and dysplasia treatment, during which the frequency of mask use was 16 % [32]. Although high-filtration masks can be worn to filter any residual plume that has not been evacuated, they should not be used as a substitute for LEV.

The particle sizes, surgical devices, and surgical mask and high-filtration mask ranges of the equipment used for protection are illustrated in Fig. 1.

Future perspectives

It is evident from our review of the literature that surgical smoke poses potential health risks to surgeons and OR personnel. The transmission of infectious disease through surgical smoke may occur because of the potential for generating infectious viral fragments, particularly when treating condylomas caused by papilloma virus. The presence of carcinogens in surgical smoke and their mutagenic effects have been known for over 30 years [17, 24]. Of several potential risks, we are especially concerned about the impact of surgical smoke on the respiratory systems of the OR personnel. Hence, we consider that large-scale studies of the prevalence of respiratory diseases in at-risk hospital personnel are needed to assess this impact.

Surgical smoke should be removed by a smoke evacuation system during both open and laparoscopic procedures. Manufacturers should continue to encourage this by providing smoke evacuation technology that is easy to use and effective in smoke capture. With new innovations in surgical power equipment, devices incorporating smoke reduction features may be developed. Surgeons should assess the potential dangers of surgical smoke, educate the OR staff about these dangers and encourage the use of evacuation devices to minimize potential health hazards to surgical personnel.

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Conflict of interest Kae Okoshi and co-authors have no conflicts of interest to declare.

References

1. Cushing H. Electro-surgery as an aid to the removal of intracranial tumors. With a preliminary note on a new surgical-current generator by W.T. Bovie, Ph.D., Chicago. Surg Gynecol Obstet. 1928;47:751–84.
2. NIOSH, Health Hazard Evaluation Report. HETA 85-126-1932, 1988. p. 2.

3. Hensman C, Baty D, Willis RG, Cuschieri A. Chemical composition of smoke produced by high-frequency electrosurgery in a closed gaseous environment: an in vitro study. Surg Endosc. 1998;12:1017–9.
4. Beebe DS, Swica H, Carlson N, Palahniuk RJ, Goodale RL. High levels of carbon monoxide are produced by electro-cautery of tissue during laparoscopic cholecystectomy. Anesth Analg. 1993;77:338–41.
5. Hensman C, Newman EL, Shimi SM, Cuschieri A. Cytotoxicity of electro-surgical smoke produced in an anoxic environment. Am J Surg. 1998;175:240–1.
6. Brüske-Hohlfeld I, Preissler G, Jauch KW, Pitz M, Nowak D, Peters A, et al. Surgical smoke and ultrafine particles. J Occup Med Toxicol. 2008;3.
7. Hill DS, O'Neill JK, Powell RJ, Oliver DW. 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;65:911–6.
8. Fletcher JN, Mew D, DesCoteaux JG. Dissemination of melanoma cells within electrocautery plume. Am J Surg. 1999;178:57–9.
9. Nduka CC, Poland N, Kennedy M, Dye J, Darzi A. Does the ultrasonically activated scalpel release viable airborne cancer cells? Surg Endosc. 1998;12:1031–4.
10. Ott DE, Moss E, Martinez K. Aerosol exposure from an ultrasonically activated (Harmonic) device. J Am Assoc Gynecol Laparosc. 1998;5:29–32.
11. Zhao C, Kim MK, Kim HJ, Lee SK, Chung YJ, Park JK. Comparative safety analysis of surgical smoke from transurethral resection of the bladder tumors and transurethral resection of the prostate. Urology. 2013;82(744):e9–14.
12. Takahashi H, Yamasaki M, Hirota M, Miyazaki Y, Moon JH, Souma Y, et al. Automatic smoke evacuation in laparoscopic surgery: a simplified method for objective evaluation. Surg Endosc. 2013;27:2980–7.
13. Al Sahaf OS, Vega-Carrascal I, Cunningham FO, McGrath JP, Bloomfield FJ. Chemical composition of smoke produced by high-frequency electrosurgery. Ir J Med Sci. 2007;176:229–32.
14. Lin YW, Fan SZ, Chang KH, Huang CS, Tang CS. A novel inspection protocol to detect volatile compounds in breast surgery electrocautery smoke. J Formos Med Assoc. 2010;109:511–6.
15. Gianella M, Hahnloser D, Rey JM, Sigrist MW. Quantitative Chemical analysis of surgical smoke generated during laparoscopic surgery with a vessel-sealing device. Surg Innov. 2013. doi:10.1177/1553350613492025.
16. Gatti JE, Bryant CJ, Noone RB, Murphy JB. The mutagenicity of electrocautery smoke. Plast Reconstr Surg. 1992;89:781–4.
17. Tomita Y, Mihashi S, Nagata K, Ueda S, Fujiki M, Hirano M, et al. Mutagenicity of smoke condensates induced by CO_2-laser irradiation and electrocauterization. Mutat Res. 1981;89:145–9.
18. McKinley IB Jr, Ludlow MO. Hazards of laser smoke during endodontic therapy. J Endod. 1994;20:558–9.
19. Capizzi PJ, Clay RP, Battey MJ. Microbiologic activity in laser resurfacing plume and debris. Lasers Surg Med. 1998;23:172–4.
20. Ferenczy A, Bergeron C, Richart RM. Human papillomavirus DNA in CO_2 laser-generated plume of smoke and its consequences to the surgeon. Obstet Gynecol. 1990;75:114–8.
21. Nicola JH, Nicola EM, Vieira R, Braile DM, Tanabe MM, Baldin DH. Speed of particles ejected from animal skin by CO_2 laser pulses, measured by laser Doppler velocimetry. Phys Med Biol. 2002;47:847–56.
22. Gloster HM Jr, Roenigk RK. Risk of acquiring human papillomavirus from the plume produced by the carbon dioxide laser in the treatment of warts. J Am Acad Dermatol. 1995;32:436–41.
23. Taravella MJ, Weinberg A, May M, Stepp P. Live virus survives excimer laser ablation. Ophthalmology. 1999;106:1498–9.
24. Choi SH, Kwon TG, Chung SK, Kim TH. Surgical smoke may be a biohazard to surgeons performing laparoscopic surgery. Surg Endosc. 2014. doi:10.1007/s00464-014-3472-3.
25. Fan JKM, Chan FSY, Chu KM. Surgical smoke. Asian J Surg. 2009;32:253–7.
26. Garden JM, O'Banion MK, Shelnitz LS, Pinski KS, Bakus AD, Reichmann ME, et al. Papillomavirus in the vapor of carbon dioxide laser-treated verrucae. JAMA. 1988;259:1199–202.
27. Baggish MS, Poiesz BJ, Joret D, Williamson P, Refai A. Presence of human immunodeficiency virus DNA in laser smoke. Lasers Surg Med. 1991;11:197–203.
28. Fitzgerald JE, Malik M, Ahmed I. A single-blind controlled study of electrocautery and ultrasonic scalpel smoke plumes in laparoscopic surgery. Surg Endosc. 2012;26:337–42.
29. Baggish MS, Elbakry M. The effects of laser smoke on the lungs of rats. Am J Obstet Gynecol. 1987;156:1260–5.
30. Ball K. Update for nurse anesthetists. Part 1. The hazards of surgical smoke. AANA J. 2001;69:125–32.
31. Ulmer BC. The hazards of surgical smoke. AORN J. 2008;87:721–34.
32. Edwards BE, Reiman RE. Comparison of current and past surgical smoke control practices. AORN J. 2012;95:337–50.
33. Laser/electrosurgery plume. (The Occupational Safety and Health Administration (OSHA) web site) https://www.osha.gov/SLTC/laserelectrosurgeryplume/. Accessed 16 Oct 2014.
34. Diathermy and surgical smoke. (The Health and Safety Executive (HSE) web site) http://www.hse.gov.uk/healthservices/diathermy-emissions.htm. Accessed 16 Oct 2014.
35. Surgical Smoke. (British Occupational Hygiene Society web site) http://www.bohs.org/uploadedFiles/Groups/Pages/Surgical_smoke.pdf. Accessed 16 Oct 2014.
36. Kubo H. Medical engineering, electrical instruments and medical gas, guideline for surgical practice (in Japanese). Nihon Shujutsu Igaku Kaishi. 2013;34:s98–113.
37. Alp E, Bijl D, Bleichrodt RP, Hansson B, Voss A. Surgical smoke and infection control. J Hosp Infect. 2006;62:1–5.
38. American College of Chest Physicians. Aerosol consensus statement. Consensus conference on aerosol delivery. Chest. 1991;100:1106–9.
39. Gates MA, Feskanich D, Speizer FE, Hankinson SE. Operating room nursing and lung cancer risk in a cohort of female registered nurses. Scand J Work Environ Health. 2007;33:140–7.
40. Pukkala E, Martinsen JI, Lynge E, Gunnarsdottir HK, Sparen P, Tryggvadottir L, et al. Occupation and cancer—follow-up of 15 million people in five Nordic countries. Acta Oncol. 2009;48:646–790.
41. Navarro-Meza MC, Gonzalez-Baltazar R, Aldrete-Rodriguez MG, Carmona-Navarro DE, Lopez-Cardona MG. Respiratory symptoms caused by the use of electrocautery in physicians being trained in surgery in a Mexican hospital. Rev Peru Med Exp Salud Publica. 2013;30:41–4.
42. Ball K. Compliance with surgical smoke evacuation guidelines: implications for practice. AORN J. 2010;92:142–9.
43. Ball K. Surgical smoke evacuation guidelines: Compliance among perioperative nurses. AORN J. 2010;92:e1–23.
44. Le Moual N, Varraso R, Zock JP, Henneberger P, Speizer FE, Kauffmann F, et al. Are operating room nurses at higher risk of severe persistent asthma? The nurses' health study. J Occup Environ Med. 2013;55:973–7.
45. Hallmo P, Naess O. Laryngeal papillomatosis with human papillomavirus DNA contracted by a laser surgeon. Eur Arch Otorhinolaryngol. 1991;248:425–7.
46. Weld KJ, Dryer S, Ames CD, Cho K, Hogan C, Lee M, et al. Analysis of surgical smoke produced by various energy-based

instruments and effect on laparoscopic visibility. J Endourol. 2007;21:347–51.
47. Heinsohn PA, Jewett DL, Balzer L, Bennett CH, Seipel P, Rosen A. Aerosols created by some surgical power tools: particle size distribution and qualitative hemoglobin content. Appl Occup Environ Hyg. 1991;6:773–6.
48. Nezhat C, Winer WK, Nezhat F, Nezhat C, Forrest D, Reeves WG. Smoke from laser surgery: is there a health hazard? Lasers Surg Med. 1987;7:376–82.
49. Wisniewski PM, Warhol MJ, Rando RF, Sedlacek TV, Kemp JE, Fisher JC. Studies on the transmission of viral disease via the CO_2 laser plume and ejecta. J Reprod Med. 1990;35:1117–23.
50. Barrett WL, Garber SM. Surgical smoke—a review of the literature. Is this just a lot of hot air? Surg Endosc. 2003;17:979–87.
51. Pierce JS, Lacey SE, Lippert JF, Lopez R, Franke JE. Laser-generated air contaminants from medical laser applications: a state-of-the-science review of exposure characterization, health effects, and control. J Occup Environ Hyg. 2011;8:447–66.
52. Agents classified by the IARC monographs, vol. 1–109. (The International Agency for Research on Cancer (IARC) web site) http://monographs.iarc.fr/ENG/Classification/. Accessed 16 Oct 2014.
53. EH40/2005 Workplace Exposure Limits. (Health and Safety Executive web site) http://books.hse.gov.uk/hse/public/saleproduct.jsf?catalogueCode=9780717664467. Accessed 16 Oct 2014.
54. Wu JS, Luttmann DR, Meininger TA, Soper NJ. Production and systemic absorption of toxic byproducts of tissue combustion during laparoscopic surgery. Surg Endosc. 1997;11:1075–9.
55. Sagar PM, Meagher A, Sobczak S, Wolff BG. Chemical composition and potential hazards of electrocautery smoke. Br J Surg. 1996;83:1792.
56. Tseng HS, Liu SP, Uang SN, Yang LR, Lee SC, Liu YJ, et al. Cancer risk of incremental exposure to polycyclic aromatic hydrocarbons in electrocautery smoke for mastectomy personnel. World J Surg Oncol. 2014;12:31.
57. Agency for Toxic Substances and Disease Registry. Toxicological Profile for Toluene (Department of Health and Human Services web site) http://www.atsdr.cdc.gov/ToxProfiles/TP.asp?id=161&tid=29. Accessed 16 Oct 2014.
58. Ferenczy A, Bergeron C, Richart RM. Carbon dioxide laser energy disperses human papillomavirus deoxyribonucleic acid onto treatment fields. Am J Obstet Gynecol. 1990;163:1271–4.
59. Ikramuddin S, Lucus J, Ellison EC, Schirmer WJ, Melvin WS. Detection of aerosolized cells during carbon dioxide laparoscopy. J Gastrointest Surg. 1998;2:580–83; discussion 84.
60. Reymond MA, Schneider C, Kastl S, Hohenberger W, Kockerling F. The pathogenesis of port-site recurrences. J Gastrointest Surg. 1998;2:406–14.
61. Sawchuk WS, Weber PJ, Lowy DR, Dzubow LM. Infectious papillomavirus in the vapor of warts treated with carbon dioxide laser or electrocoagulation: detection and protection. J Am Acad Dermatol. 1989;21:41–9.
62. Armstrong DN, Ambroze WL, Schertzer ME, Orangio GR. Harmonic Scalpel vs. electrocautery hemorrhoidectomy: a prospective evaluation. Dis Colon Rectum. 2001;44:558–64.
63. Amaral JF. The experimental development of an ultrasonically activated scalpel for laparoscopic use. Surg Laparosc Endosc. 1994;4:92–9.
64. Kokosa JM, Eugene J. Chemical composition of laser-tissue interaction smoke plume. J Laser Appl. 1989;3:59–63.
65. Brandon HJ, Young VL. Characterization and removal of electrosurgical smoke. Surg Serv Manag. 1997;3:14–6.
66. Hirata S. Building equipment of surgical room, guideline for surgical practice (in Japanese). Nihon Shujutsu Igaku Kaishi. 2013;34:s131–6.
67. Schultz L. An analysis of surgical smoke plume components, capture, and evacuation. AORN J. 2014;99:289–98.
68. Coia JE, Ritchie L, Adisesh A, Makison Booth C, Bradley C, Bunyan D, et al. Guidance on the use of respiratory and facial protection equipment. J Hosp Infect. 2013;85:170–82.
69. Benson SM, Novak DA, Ogg MJ. Proper use of surgical n95 respirators and surgical masks in the OR. AORN J. 2013;97:457–67.
70. Chemical Sampling Information (The Occupational Safety and Health Administration (OSHA) web site). https://www.osha.gov/dts/chemicalsampling/toc/toc_chemsamp.html. Accessed 16 Oct 2014.