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REVIEW ARTICLE

Surgical smoke and the anesthesia provider

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Abstract
Surgical smoke generated by use of electrosurgical units (ESUs), lasers, and ultrasonic scalpels constitutes a physical, chemical, and biological hazard for anesthesia personnel. Inhalation of particulate matter with inflammatory consequences, pulmonary injury from products of tissue pyrolysis, exposure to mutagens and carcinogens, and the transmission of human papillomavirus (HPV) and possibly other pathogens represent a spectrum of adverse effects associated with the occupational exposure to surgical plume. While adequate operating room ventilation and use of high filtration-efficiency masks offer some protection from these conditions, the most effective method of safeguarding against surgical smoke involves its removal with a dedicated smoke evacuation device (SED). Despite the fact that many professional and governmental agencies have endorsed widespread usage of SEDs, anesthesia providers have been largely silent on this subject, with few reports within the field of anesthesiology and perioperative medicine regarding these hazards. SED use is relatively infrequent in most surgeries, and this condition reflects surgeons' reluctance to employ these devices, likely resulting from lack of education and less than optimal technology. Anesthesia societies and academic centers can serve critical roles in advocating employment of SEDs in much the same way that they have supported perioperative smoking cessation.

Keywords Surgical smoke · Hazards · Smoke evacuation

Introduction

In recent years, anesthesiologists have taken a front row seat in an international movement to encourage smoking cessation [1, 2]. Recently, the Japanese Society of Anesthesiologists published perioperative smoking cessation guidelines [3], and as long ago as 2006, the American Society of Anesthesiologists (ASA) assembled a "Smoking Cessation Initiative Task Force" for the purpose of promoting abstinence from tobacco usage in patients [4]. Similar endeavors have occurred in multiple other countries [2, 5–7]. In addition—likely related to the widely published adverse effects of smoking on chronic health as well as on perioperative outcomes—anesthesiologists have either quit or refrained from cigarette smoking to a greater degree than the other elements of the general population [7, 8]. Despite these attitudes and modifications in personal choices, chronic inhalation of smoke from operating room sources remains common in most anesthesia practices, and this problem largely has been unaddressed within the anesthesia community.

Specifically and somewhat counter-intuitively, anesthesia providers have not taken a lead role in either education regarding the hazards of surgical smoke or in advocating for consistent protection from operating room plume. While there has been a relative increase in the awareness of these hazards in multiple settings including the lay public [9], standard anesthesia texts continue either not to mention this widespread occupational problem [10, 11], or choose to address it in a superficial manner [12]. Some general reviews of occupational hazards in anesthesia publications have covered the topic within the broad category of "chemical hazards," but the last ASA publication on "Occupational Hazards and Health for Anesthesiologists" contains no discussion of surgical smoke [13]. The most recent focused review of this topic in the anesthesia literature appeared in the American Association of Nurse Anesthetists Journal almost 20 years ago [14]; nearly all of the subsequent medical educational material specific to surgical smoke has been

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published in nursing journals, surgical journals, or journals associated with the other subspecialties.

Interestingly—despite the widespread prevalence of occupational hazards related to the practice of anesthesia and the relatively common adverse consequences associated with them—anesthesiologists remain remarkably uninformed about the nature of many of these problems and the available methods for self-protection. A recent survey of 158 anesthesiologists from a tertiary care hospital demonstrated that more than 50% had inadequate knowledge concerning multiple common workplace hazards [15]. Anesthesia practice often reflects this ignorance, and the apparent lack of concern in the anesthesia community for the harmful effects of surgical smoke may well be rooted in similar unawareness.

Health hazards of surgical smoke

Extent of exposure

Surgical smoke derives from the use of ESUs, laser devices, and ultrasonic scalpels. In all of these processes, thermal destruction of tissue results in "smoke" consisting 95% of water vapor (from release and subsequent boiling of intracellular contents) and 5% of organic byproducts of combustion, cells, and cellular debris [16]. This latter mixture is responsible for the chemical and biological adverse consequences of smoke inhalation. Importantly, smoke particle size may relate to hazard potential, with smaller particles (commonly associated with ESU usage) having an increased likelihood of chemical adverse effects, and larger particles (commonly from lasers or ultrasonic scalpels) having a propensity for transmission of biological hazards [16, 17].

Attempts at quantifying surgical smoke inhalation have employed cigarette analogies, although the applicability of such analogies lacks scientific rigor. These cigarette comparisons derive from a study that determined the mass of tissue ablated by in vitro cauterization of human and porcine tissue for 5 min with monopolar diathermy [16]. Predicated on an electronic recording of diathermy times in a plastic surgery operating room over a 2-month period, this investigation calculated that ESU use in the latter setting was associated with the daily vaporization of approximately 5 g of tissue. By further extension, employing data related to the mutagenicity of ESU smoke condensates (showing that smoke produced from 1 g of tissue vaporization had an equivalent mutagenic effect to 6 unfiltered cigarettes), these same investigators suggested that average daily plastic surgery resulted in plume with potential carcinogenic consequences comparable to smoking 27–30 unfiltered cigarettes.

Based on the latter publication, it has been suggested that breathing smoke from a single operation may be roughly equivalent (in terms of mutagenicity) to smoking one pack of cigarettes. However, this analogy is misleading. Surgical smoke normally is inhaled following some degree of room air dilution. As such, more accurately, breathing operating room plume can be compared with exposure to "second-hand" (passive) inhalation of smoke from multiple cigarettes—since first-hand cigarette smoke is directly inhaled without such dilution.

Furthermore, the precise exposure of anesthesia providers to surgical plume likely depends on multiple factors, including (1) type of surgeries, including target tissues and surgical technique (for example, ophthalmologic procedures typically involve little if any thermoablation, while other procedures like breast reconstructions involve extensive ESU usage) [18]; (2) relative use of smoke scavenging technology; and (3) operating room airflow: depending on state building codes, surgical suites have a minimum of 15–20 air exchanges per hour, each involving 3–4 exchanges with outdoor air (recommendations of the Center for Disease Control (CDC), the American National Standards Institute, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, and the American Society for Healthcare Engineering) [19, 20]. Regardless of such considerations, most anesthesia providers and other operating room personnel are exposed to significant levels of smoke inhalation on a regular basis related to use of ESU, laser, and ultrasonic scalpels.

Particulate matter

Breathing surgical smoke has been associated with a wide variety of acute and chronic illnesses [21, 22]. These disease states have been well documented in animals [18, 23–30], with some human data as well [21, 31–34]. The etiology of such pathology may relate to deposition of particulate matter (PM) in pulmonary tissue: these particles have been shown to induce inflammatory responses with alveolar congestion and interstitial pneumonia (in animal models), and emphysematous changes (in humans) [9, 21, 35–37]. Furthermore, long-term exposure to surgical smoke has been correlated with an increased risk of asthma and pneumonia in operating room personnel [34, 38].

The propensity for PM-associated tissue injury depends to some extent on maximum particle diameters, which vary according to the source of surgical smoke: ESU PM is characterized by diameters of 0.07–0.42 μm, laser PM by diameters of 0.1–0.8 μm, and ultrasonic scalpel PM by diameters of 0.35–6.5 μm [9, 22, 39]. In this context, it is noteworthy that particles with maximum diameters smaller than 2 μm are preferentially deposited in the bronchioles and alveoli [26, 31, 35, 36]. Furthermore, ultrafine PM (UFPM; maximum diameter ≤ 0.1 μm) generated by ESU usage—in addition to penetrating into alveoli [26, 40–43]—can enter the systemic circulation and result in oxidative stress [9, 44].

The concentration of UFPM in operating room air not only varies with the source of surgical smoke, but also with the duration of ESU usage, the type of tissue (surgery), and the type of ventilation system [26]. Romano et al. measured the UFPM concentrations during surgeries employing different types of ESU (monopolar, bipolar, and argon diathermy). In general, and as might be expected, longer durations of ESU usage were associated with higher UFPM numbers. Also, per unit time of ESU usage, liver resections and gallstone surgery generated larger amounts of such particles than Whipple, breast, or skin surgery. Perhaps most importantly, surgeries performed in operating rooms equipped with a unidirectional downward airflow ventilation (UDV) systems were associated with significantly lower UFPM concentrations compared with similar procedures performed in operating rooms equipped with the standard upward displacement (UWD) airflow systems (on the average 13 times lower in the anesthesia work area during liver resections in this study). In UDV operating rooms, high-velocity airflow patterns are believed to sweep UFPM away from the surgical zone into surrounding extraction grille areas—containing high-efficiency particulate air (HEPA) filters—with greater efficiency compared with UWD rooms that are associated with relatively low-volume and low-velocity currents, and that also carry UFPM floor contaminants across critical personnel areas.

Regardless of the ventilation system employed, these extremely small particles spread beyond the immediate surgical field, and significant spikes in UFPM concentration are observed intermittently during surgery within the entire operating room area, including within the anesthesia workspace [26, 45]. This material is able to penetrate the filters of standard operating room masks (with pore sizes of 5–15 μm) as well as high-performance masks such as the N95 respirator (with pore sizes of 0.3 μm) [26]. In fact, UFPM pass through normal SEDs despite the presence of one or more HEPA filters [46, 47].

Interestingly, the health consequences of chronic PM inhalation in individuals outside the operating room have been better detailed than the adverse effects of comparable exposure during surgery. In its regulatory role, the United States Environmental Protection Agency notes that chronic exposure to aerosolized PM has a causal relationship to ischemic heart disease, congestive heart failure, and bronchospastic pulmonary disease [9]. The American Heart Association specifically has stated that chronic inhalation of PM with diameters ≤ 2.5 μm is a risk factor for cardiovascular mortality [44], consistent with an epidemiologic study of postmenopausal women published by Miller and co-workers in 2007 [48]. Other investigations link breathing UFPM with neurologic illness and adverse birth outcomes [9, 49].

Chemical toxicity, mutagenicity, and carcinogenicity

In addition to the hazards posed by PM inhalation, nearly 150 volatile organic compounds (VOCs) with potential harmful effects have been identified as vaporized byproducts of tissue pyrolysis, and it has been estimated that the true number of such compounds exceeds 600 [50–53]. Drugs administered to patients can alter the chemical composition of surgical smoke and may be present in significant concentrations in aerosolized form—including sevoflurane [9, 54, 55]. The precise mixture of smoke toxins depends both on the type of diathermy and the tissue being ablated. The most prevalent of these compounds generated by ESU are hydrocarbons, nitriles, fatty acids, and phenols, and are benzene, formaldehyde, acrolein, and polycyclic aromatic hydrocarbons when lasers are employed [36]. Epidermal tissue pyrolysis results in high levels of vaporized toluene, ethylbenzene, and xylene, while smoke derived from adipose tissue contains lower levels of toluene and increased levels of aldehydes [9, 56].

Inhalation of these substances is correlated with a wide spectrum of problems affecting most major organ systems. For this reason, the permitted short-term and chronic exposure levels of many of these toxins are addressed by the Occupational Safety and Health Administration (OSHA), the National Institute for Occupational Safety and Health (NIOSH), and the United States Department of Health and Human Services [36]. Surgical smoke routinely contains these compounds in concentrations that are orders of magnitude higher than the recommended exposure limits [9]. Corresponding noxious effects include eye, nose, and throat irritation [18], and the development of acute and chronic pulmonary pathology [21, 36].

In addition to their tissue toxic effects, many of these organic byproducts of pyrolysis are established carcinogens [21, 36]. Collection of plume from a point 40–45 cm above cautery level (face height) demonstrated concentrations of several of these carcinogens that were an order of magnitude higher than occurs in second-hand cigarette smoke [57]. Surgical smoke also has been shown to possess both mutagenic and cytotoxic effects when studied by standard laboratory assays [36, 58]. However, despite the known carcinogenicity of many of the compounds in operating room air (and multiple in vitro and animal studies demonstrating both the mutagenic and carcinogenic properties of diathermy plume), long-term operating exposure to surgical smoke does not appear to increase the risk of lung cancer [21, 29, 38]. Comparable studies have not been performed for other cancers.

Biological hazards

Potential exposure to biological entities via surgical smoke includes transmission of viable tumor cells, bacteria, and viruses. On a theoretical basis, smoke from laser and ultrasonic scalpel use are believed to have a greater propensity for spread of biologic entities, because it is relatively cooler [9, 21].

The presence of viable tumor cells in surgical smoke has been demonstrated both in animal and human studies. These elements have been potentially linked to port-site recurrence of disease in patients who underwent laparoscopic tumor resection [36, 59, 60]. However, this theoretical "chimney effect" phenomenon—wherein aerosolized cancer cells moving through laparoscopic ports deposit on trocars and result in tumor metastases—likely occurs only in the presence of carcinomatosis [60, 61]. Despite such considerations, no in vivo evidence exists for transmission of patient tumors to operating room personnel via surgical smoke [9].

Multiple strains of viable bacteria, including *Mycobacterium tuberculosis* (TB), have been cultured from surgical smoke [18], but again, no studies exist demonstrating aerosolized transmission to surgical staff. Data concerning most viruses—either intact virions or viral deoxyribonucleic acid (DNA)—are similar. Poliovirus, hepatitis B virus, and human immunodeficiency virus (HIV) have been recovered from surgical plume [21, 62–64]. In fact, HIV DNA is detectable in smoke for up to 14 days after its production, although its infectivity has not been established [29, 30, 63]. However, there are no reports of surgical personnel acquiring diseases related to these pathogens via plume—even though theoretical mechanisms exist for aerosolized transmission of some of the infectious agents.

HPV transmission via surgical smoke is the exception. This process likely applies to three clinical entities: (1) oral warts (HPV serotypes 6 and 11); (2) oropharyngeal cancers (HPV serotypes 16 and 18); and (3) recurrent respiratory papillomatosis, including both laryngeal papillomatosis (documented) and pulmonary papillomatosis (hypothesized) (HPV serotypes 6 and 11) [36, 65–67]. While there are no randomized studies, several reports detail isolation of HPV DNA from surgical plume associated with both laser and ESU use [36, 65]. In addition, studies have demonstrated that HPV from surgical smoke can be isolated from the nasolabial folds and nostrils of unprotected operating room personnel exposed to plume, but not from the mucosa of comparable personnel using plume protection [68, 69]. Recently, HPV DNA with identical genotypes was detected both in the surgical smoke and nasal epithelial cells of two surgeons performing loop electrocautery excision procedures [65]. Of note, however, subsequent nasopharyngeal swabs from these same physicians after 3–6 months tested negative for HPV DNA (and remained negative at 12 and 24 months with no clinical manifestations of HPV-related disease), indicating lack of persistent viral infection. While HPV viability in these settings could not be demonstrated (due to lack of an appropriate bioassay), the infectivity of bovine papillomavirus isolated from smoke and transmitted by cutaneous inoculation (not by inhalation) has been established [70]. As such, current evidence for transmission of HPV infection via surgical smoke is very suggestive, but not conclusive.

Several additional case reports are pertinent to the above analysis. Laryngeal papillomatosis has been reported both in a surgeon who routinely performed laser ablation of colorectal and anorectal papillomas in the absence of an SED [66], and in a nurse who assisted with laser removal of anorectal warts in an improperly ventilated utility room [67]. Likewise, a 2013 report documented the occurrence of HPV-16-positive tonsillar carcinomas in two surgeons with an extensive history of cervical laser ablations, and no identifiable risk for HPV or oropharyngeal cancer [71].

Protection from surgical smoke hazards

Three distinct methods exist for the protection of anesthesia providers from the hazards of surgical smoke. These include: (1) room ventilation, (2) face masks, and (3) SEDs. Despite the fact that these methodologies have varying efficacies to protect against plume in different circumstances, their proper use predictably can minimize many of the adverse effects associated with exposure to products of tissue pyrolysis.

For reasons related to infection control, CDC-NIOSH guidelines recommend a minimum of 15 exchanges of filtered air per hour in U.S. operating rooms, of which 20% must be performed with fresh air [19, 20]. Other regulatory and advisory agencies recommend higher numbers. Although such intervention does reduce the risk of surgical site infection due to airborne vectors, protection from surgical plume solely based on room ventilation is inadequate [19, 72].

Likewise—predicated on pore size alone—masks theoretically are only partially effective at preventing the exposure of anesthesia providers to smoke hazards [21]. Standard surgical masks (designed to protect from aerosolized droplets) have pores that are 5–15 μm in diameter, whereas N-95 high filtration-efficiency masks filter particles with maximum diameters ≥ 0.3 μm, and "laser" HEPA filter masks are designed to filter particles with maximum diameters ≥ 0.1 μm. Given that the mean diameter of ESU-generated surgical smoke PM is 0.07 μm [26], and that most viral pathogens, including HPV, hepatitis B, hepatitis C, and HIV, have largest dimensions smaller than 0.3 μm (and most smaller than 0.1 μm) [14], surgical masks likely provide incomplete protection against both PM and biologic elements of plume.

The ability of masks to provide protection in this setting depends not only on pore size but also on the mask fit (i.e., if there are gaps around the mask sides, smoke will be inhaled via these gaps [14, 18, 21, 46]) and the integrity of the filter system (dampness may adversely affect filtration efficiency [18]). Predictably, studies using monodisperse latex spheres and sodium chloride aerosols with PM sizes smaller than 5 μm (0.08, 0.9, 2.0, and 3.1 μm) [73, 74], as well as live influenza virus [75], have demonstrated widespread penetration of standard surgical masks. N95 and N100 masks are somewhat more effective [36, 76], but there are significant practical problems associated with wearing these masks on a regular basis during work [77]. Largely for this reason, only 1–2% of operating room personnel routinely utilize these latter high-filtration masks [21, 78].

Furthermore, most masks act as poor barriers against VOCs in surgical smoke. The addition of activated charcoal fiber to HEPA filters (termed "high efficiency gas absorption" or HEGA filters), however, will increase the effectiveness of mask protection in this regard [79]. A 2018 study showed that these latter filters significantly reduced exposure of surgical personnel to known carcinogens in surgical plume [80]. To date, use of HEGA filters has not been a common clinical practice.

Removal of plume from the operating room atmosphere may provide the best protection against smoke exposure. Wall suction, however, is less than entirely effective for this purpose. This system is designed to remove liquids from the surgical field and delivers approximately 5 cubic feet per minute (CFM) of suction, compared with dedicated SEDs that provide 35–50 CFM of suction [19, 72]. Furthermore, consistently maintaining the position of a suction tip within 2 cm of the smoke source (a distance that is critical to maximize smoke evacuation [81]) is often difficult, and routinely impairs the surgeon's view of the tissue requiring surgical attention [19]. In addition, these devices frequently become obstructed with tissue and solid debris, further reducing or eliminating their evacuation pull. Finally, once the smoke is delivered to the suction canisters, at least a portion of it escapes into the operating room [9], and the other portion is delivered to the central vacuum system where it can accumulate and potentially cause additional hazards [18].

Intraperitoneal smoke generated during laparoscopic surgery poses several different challenges. During laparoscopy, this plume either leaks from trocar sites or often is released by the surgeon into the operating room air [82]. Furthermore, because this smoke has accumulated over a period of time (and, therefore, is less diffuse than smoke produced in open procedures), and it is released as a directed jet, exposure of anesthesia and surgical personnel to significant concentrations of plume is relatively common [21, 37]. HEPA or ultra-low particulate air (ULPA) filters that attach to laparoscopic trocars allow for filtration of smoke contents before it is removed into the central vacuum system, although flow rates through these devices need to be less than carbon dioxide insufflation rates (typically 4–6 L per minute) to maintain a pneumoperitoneum [9, 83]. At the end of laparoscopic procedures, intraperitoneal gas contents optimally can be removed through a filtered evacuation system, rather than being released into the operating room environment [21, 84].

Perhaps, the most complete method for removal of surgical smoke involves a dedicated SED applied to the ESU or ultrasonic scalpel, or in the area of laser tissue ablation [36, 85, 86]. Although SEDs have demonstrated variable efficiency in removing VOCs [87, 88], they almost entirely eliminate surgical smoke elements larger than 0.12 μm in diameter [36]—one reason dedicated SEDs likely provide more protection from surgical plume compared with wall suction devices held by assistants [89, 90]. For example, the concentration of UFPM measured at surgical mask level was five times lower during use of SEDs than during use of a separate handheld aspiration device [47].

A dedicated SED consists of three basic components: a capture device (either free standing or fitted over an electrosurgical pencil), a vacuum system capable of generating 30–50 CFM of suction, and a filtration unit (Fig. 1). Filters are commonly rated by the particle size least likely to be trapped by the device ("most penetrating particle" or MPP) [18, 91]. Smoke products larger than the MPP often do not fit through the filter pores; smaller particles are channeled to the SED vacuum exhaust.

The filters commonly employed in these devices are either HEPA or ultra-low particulate air (ULPA) filters, or a combination of these units. HEPA filters clear 99.7% of particles with diameters $\geq$ 0.3 μm, while ULPA filters remove at least 99.999% of particles with diameters $\geq$ 0.12 μm [84]. The highest efficiency ULPA filters are termed very-large-scale integrated (VLSI) filters. Many systems utilize one of these types of filters together with activated charcoal that can eliminate 85% of VOCs from smoke plume [80]. Despite such product design, after use of SEDs, remaining levels of these latter compounds still may exceed recommended thresholds [36, 87]. In general, HEPA and ULPA (including VLSI) filters are most efficient for removal of fine PM; biological contaminants of smoke are best eliminated from plume via ULPA (and VLSI) and activated carbon filters; and VOCs are most effectively cleared using activated carbon filters [18].

Proper use of SEDs may be critical for optimal smoke protection. HEPA and ULPA filters need to be replaced on a regular schedule to maintain operating efficiency, as collected particles can degrade and be released into the surgical suite [9]. Furthermore, it is essential to connect SEDs to the ventilation exhaust, since otherwise both biological and non-biological elements not filtered by the system are re-circulated into the operating room air. Correct intraoperative use

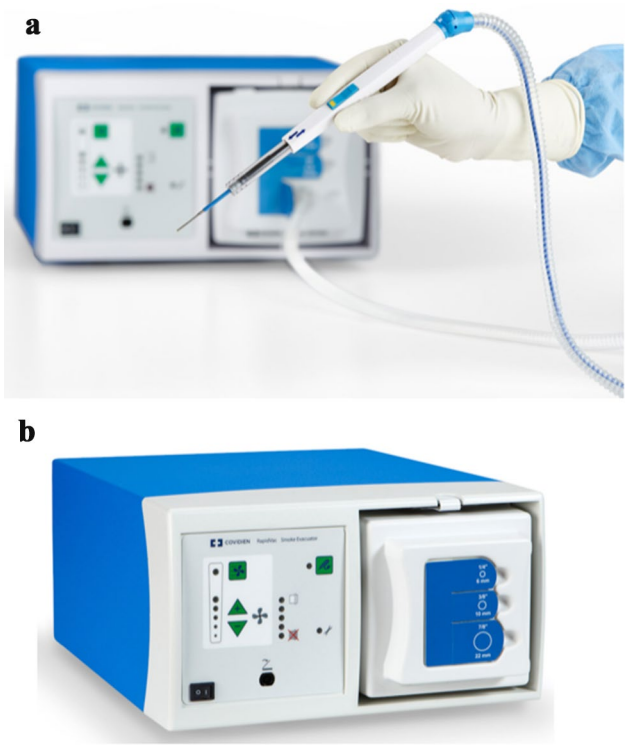

Fig. 1 Smoke evacuation device showing (**a**) electrosurgical pencil containing capture system surrounding protruding electrode connected to (**b**) vacuum-driven smoke evacuator with replaceable ULPA filtration unit. ©2020 Medtronic. All rights reserved. Used with permission of Medtronic

of SEDs also includes activation of the SED either simultaneously or immediately prior to thermoablation device activation, and for 5–10 s after termination of device use. Many SEDs' systems are designed to achieve this goal automatically [92].

Economics

In addition to health concerns, the economics of smoke evacuation play a significant role in institutional decisions regarding whether to employ SEDs. Specifically, the cost effectiveness of these systems is an important consideration, particularly given the relative scarcity of unequivocal data linking persistent human disease with surgical smoke exposure. Precise cost expenditures associated with routine smoke evacuation are difficult to calculate, partially due to the proliferation of companies manufacturing these products. However, rough figures can be estimated. Most SEDs currently cost between 1000 and 2000 US dollars (USD). Expenses associated with ULPA filters (with variable life expectancies depending upon usage) and single patient-use accessories including smoke evacuation tubing and electrosurgical pencils are commonly in the order of several hundred USD.

Guidelines and regulations concerning surgical smoke

In varying contexts, multiple professional and governmental agencies have recommended the use of SEDs. OSHA only indirectly addresses this issue via its "General Duty Clause," wherein it asserts that "each employer shall furnish…a place of employment that is free of recognized hazards that are causing or likely to cause death or serious physical harm to his employees" [18, 19]. On its website, NIOSH suggests use of SEDs when "considerable plume is generated" (https://www.cdc.gov/niosh/topics/healthcarehsps/smoke.html). The 2019 CDC Guidelines for Environmental Infection Control in Health-Care Facilities limits its SED recommendation to tissue ablations involving HPV and TB [20]. The Association of Perioperative Registered Nurses (AORN) is more comprehensive in its guidelines: "The health care organization should provide for a surgical smoke-free work environment…The perioperative team should use a smoke evacuation system (e.g. smoke evacuator, in-line filter) to evacuate all surgical smoke. The decision to evacuate or not to evacuate surgical smoke should not be made at the discretion of an individual practitioner." [93] The Emergency Care Research Institute, the American National Standards Institute, and the American Association of Laser Medicine and Surgery make similar suggestions [18]. Likewise, the Japanese Association for Operative Medicine has advocated use of SEDs [94], although most surgical personnel in Japan (including anesthesia providers) remain uninformed about the hazards of smoke [21]. In contrast, anesthesia societies including the ASA and the International Anesthesia Research Society have been silent in this regard.

In some circumstances, legislation limiting surgical smoke exposure has come into effect. For example, several states recently have mandated use of SEDs through legislative statutes. Furthermore, Denmark, Australia, New Zealand, and Canada now regulate the evacuation of surgical plume as a matter of law [95–97].

Reasons for lack of smoke evacuation

Despite such guidelines and recommendations, a 2011 NIOSH survey found that only approximately 50% of U.S. operating rooms employed local exhaust evacuation during laser use, and approximately 15% during use of ESU.

Of the 4,533 respondents in this report, 21% were anesthesiologists (51% were perioperative nurses). The study concluded that control of surgical smoke was not a priority in the majority of these settings, and consequently, nearly half of operating room personnel received no training related to surgical smoke and one-third did not have the option of device-related smoke evacuation [36, 97]. These CDC-NIOSH findings are consistent with a web-based survey conducted among AORN members in 2008 [98]. At approximately the same time, use of SEDs in the United Kingdom was even lower: a 2007 survey showed that only 3 of 98 surgeons routinely used this technology [81, 98].

In the AORN web-based survey cited above, the relative use of SEDs was directly linked to surgeons' perceptions of the hazards of operating room plume [98], and multiple studies have suggested that better and more widespread education can increase use of smoke protective measures [36, 99]. In 2016, a team of perioperative nurses and educators demonstrated a relatively small but measurable (15%) increase in 90-day use of SEDs following a multimodal educational program [99]. This approach (medical staff education) has been championed repeatedly by AORN [19].

A consistent theme associated with the underuse of SEDs is surgeon resistance or refusal [21, 46, 78, 98]. Perioperative nurses and anesthesia providers often report feeling impotent to decide issues related to safe smoke practice [46, 81]. In addition to lack of education concerning the hazards of plume, surgeon reluctance to use SEDs is likely related to the bulkiness of the equipment resulting in both awkward handling and decreased visibility of the surgical field during device use [21, 78, 97, 98]. A critical element of any viable SED implementation involves a surgeon "buy-in" [19]. During one successful attempt at introduction of SEDs, surgeons were able to choose an SED-ESU "pencil" that demonstrated good hand fit, was lightweight, had unrestricted movement, and was associated with tubing that was pliable and did not tangle [19].

Noise is another reason for underuse of SEDs [21, 78, 97]. A study of efficiencies and noise levels of SEDs showed that these devices generate between 51 and 69 decibels, with the loudness largely dependent on the strength of suction [100]. Noise levels with SEDs also vary with the size and type of the tubing (corrugated tubing being noisier), and with the condition of foam padding in the smoke evacuator [101]. Certain procedures that require ESU electrode extenders (such as development of a sub-pectoral pocket during reconstructive breast surgery) do not work well with SEDs. In both of these areas—noise minimization and effective use of SEDs with ESU electrode extensions—developments in smoke evacuation engineering are needed.

Conclusion

Surgical smoke is a well-established occupational hazard for workers in the operating room. Although anesthesia providers have been strong advocates for perioperative smoking cessation, in general, they have not applied the same scrutiny to their daily working atmosphere. Specifically, there has been almost no effort from the global anesthesia community supporting educational endeavors related to surgical smoke, and no organized endeavors by anesthesia professional societies to support routine use of SEDs. With approximately 300 million operations occurring worldwide each year [102], the exposure of anesthesia personnel and other health-care providers to the physical, chemical, and biological adverse effects of plume is very significant. Given the importance of this issue, it has been suggested that surgical smoke safety should be incorporated into residency training programs, and that Accreditation Council for Graduate Medical Education funds should be allocated for this purpose [30]. While governmental bodies are beginning to introduce legislation mandating SED usage, predicated on the large collection of data documenting the adverse effects of surgical plume, anesthesia providers should consider greater support for effective removal of smoke from the operating room environment.

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