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and Other Interventional Techniques

Surgical smoke—a review of the literature

Is this just a lot of hot air?

W. L. Barrett,[1] S. M. Garber[2]

[1] Indian Health Service, Ada, OK 74820, USA
[2] Long Island Institute for Minimally Invasive Surgery, 488 Great Neck Road, Suite 300, Great Neck, NY 11021, USA

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Abstract
Background: Surgical smoke is omnipresent in the day-to-day life of the surgeon and other medical personnel who work in the operating room. In addition, patients are also exposed, especially and uniquely so in laparoscopic cases where smoke is created and trapped in a closed and absorptive space. Surgical smoke has typically been produced by electrocautery but is now ever more present in a new form with the burgeoning use of the laser and the harmonic scalpel.
Materials and methods: Several cases of transmission of human papillomavirus (HPV) from patient to treating professional via laser smoke have alerted us to the reality that surgical smoke in certain situations is far form benign. However, surgeons rarely take measures to protect themselves, their co-coworkers and patients from surgical smoke.
Results: Should we and, if so, how do we differentiate between different types of smoke and should we move toward increasing our efforts to protect ourselves, our co-workers, and patients from it?
Conclusions: This article attempts to sort through the available data and draw some reasonable conclusions regarding surgical smoke. In general, surgical smoke is a biohazard and cannot be ignored. At a minimum, surgical smoke is a toxin similar to cigarette smoke. However, other dangers exist. This is especially true in specific curcumstances such as when tissue infected with dangerous viruses is aerosolized by lasers. In addition, smoke generated by the harmonic scalpel, being a relatively cold vapor similar to laser smoke, should be further investigated for its potential ill effects and until then, looked upon with reasonable caution. Although not a high priority in most surgical cases, surgeons should support efforts to minimize OR personnel, patients, and their own exposure to surgical smoke.

Correspondence to: W. L. Barrett

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Electrocautery, laser tissue ablation, and ultrasonic (harmonic) scalpel tissue dissection all create a gaseous by-product commonly referred to as "smoke" that can be easily seen and smelled. Concern for this smoke has led to numerous investigations in an effort to determine what, if any, risks this by-product poses to surgeons, operating room (OR) personnel, and/or patients. Some of the findings from these investigations have led to significant concerns regarding the safety of surgical smoke. However, many surgeons and OR personnel argue that they have been exposed to surgical smoke for years with no ill effects.

It is easy to overextrapolate from scientific findings that demonstrate potential dangers from surgical smoke. Likewise, it is just as easy to downplay the risks due to the fact that surgical smoke is so commonplace and because typically there are no immediate ill effects. For these and other reasons, there is currently no consensus regarding what should be done about surgical smoke. Although national organizations have developed guidelines and recommendations for the handling of this by-product, no authoritative national organization currently mandates that protective measures be taken. Therefore, the opinions of and precautionary practices taken by institutions, health care facilities, and OR personnel vary widely.

The goals of this review article are to

1. Define the terminology regarding the surgically generated gaseous by-product most commonly referred to as smoke.
2. Outline what is currently known about the smoke generated by electrocautery, laser tissue ablation, and ultrasonic (harmonic) scalpel tissue dissection.
3. Discuss the proven and theoretical risks of surgical smoke.

4. Discuss the effectiveness of surgical masks in protecting OR personnel.
5. Outline the current recommendations from various authoritative and other national organizations regarding the use of control measures.
6. Discuss what can be done to minimize exposure and subsequent risk for surgeons, OR personnel, and patients.
7. Summarize and draw some reasonable conclusions.
8. Make recommendations and discuss future directions.

Terminology

The terminology of this by-product is less than straightforward. The terms "smoke," "plume," "aerosol," and "vapor" have all been used. Formally, the term "smoke" describes the products of combustion, whereas the term "vapor" describes suspended particles generated through means other than combustion. The terms "aerosol" and "plume" are more all-encompassing and incorporate combustion- and noncombustion-generated products. The terms "smoke," "plume," and, less commonly, "aerosol" are usually used to describe the product of laser tissue ablation and electrocautery, and "plume," "aerosol," and "vapor" have commonly been used to describe the product of ultrasonic dissection. For the most part, the term "smoke," although not formally correct in all cases, is used to describe this surgically generated gaseous by-product.

What is known?

General

Electrocautery, laser tissue ablation, and ultrasonic (harmonic) scalpel tissue dissection all produce a smoke or aerosol that have different properties. The mean aerodynamic size of particles generated varies greatly depending on the energy method used to create them. Electrocautery creates particles with the smallest mean aerodynamic size (0.07 μm) [1], whereas laser tissue ablation creates larger particles (0.31 μm) [2] and the largest particles are generated by the ultrasonic (harmonic) scalpel (0.35–6.5 μm) [3]. The smaller particles from any of these devices tend to travel greater distances from their point of production and travel up to 100 cm [4]. In general, smaller particles are of more concern from a chemical standpoint, and larger particles are of more concern from a biological standpoint.

The amount and content of smoke generated can vary widely from procedure to procedure. Different target tissues produce varying amounts of smoke with different characteristics. Factors that can affect the amount and content of smoke include the type of procedure, the surgeon's technique, the pathology of the target tissue (e.g., whether particular bacteria or viruses are present), the type of energy imparted, the power levels used, and the amount of cutting, coagulation, or ablating performed [5].

Table 1. Chemicals identified within electrosurgical smoke

Acetonitrile	Furfural (aldehyde)
Acetylene	Hexadecanoic acid
Acroloin	Hydrogen cyanide
Acrylonitrile	Indole (amine)
Alkyl benzene	Isobutene
Benzaldehyde	Methane
Benzene	3-Methyl butenal (aldehyde)
Benzonitrile	6-Methyl indole (amine)
Butadiene	4-Methyl phenol
Butene	2-Methyl propanol (aldehyde)
3-Butenenitrile	Methyl pyrazine
Carbon monoxide	Phenol
Creosol	Propene
1-Decene (hydrocarbon)	2-Propylene nitrile
2,3-Dihydro indene (hydrocarbon)	Pyridine
Ethane	Pyrrole (amine)
Ethene	Styrene
Ethylene	Toluene (hydrocarbon)
Ethyl benzene	1-Undecene (hydrocarbon)
Ethynyl benzene	Xylene
Formaldehyde	

Electrocautery

The chemical makeup and biological properties of electrocautery smoke have been studied in an effort to define and quantitate harmful substances present within the smoke. Numerous chemicals have been found (Table 1), some of which are hazardous and present in greater than negligible quantities.

The chemicals present in the greatest quantity in electrocautery smoke are hydrocarbons, nitriles, fatty acids, and phenols [6]. Of these, carbon monoxide (CO) and acrylonitrile are the most concerning. Other chemicals present in smaller quantities but of significant concern include hydrogen cyanide, formaldehyde, and benzene.

CO production is of particular concern in laparoscopic procedures in which smoke is trapped and concentrated in the peritoneal cavity. High levels of CO are produced during laparoscopic cholecystectomy [7]. Electrocautery during laparoscopic procedures has been shown to increase intraabdominal CO to "hazardous" levels, leading to small but significant elevations of carboxyhemoglobin (COHb) [8]. Levels of CO in the intraabdominal cavity at the end of a laparoscopic cholecystectomy have been found to be 100–1900 parts per million (ppm) [7], much higher than the 35 ppm for a 1-h exposure set by the Environmental Protection Agency (EPA) [9]. Additionally, CO is readily absorbed from the peritoneum into the bloodstream, creating a route for systemic intoxication [10].

Acrylonitrile is a colorless, volatile liquid that is easily absorbed through the skin and lungs and exerts its toxicity by liberating cyanide [11]. The Occupational Safety and Health Administration (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 1.0–1.6 ppm, just under the established limit [8].

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. In addition, it can act synergistically with CO in impairing tissue oxygenation. The U.S. Department of Health and Human Services has set the short-term exposure limit at 10 ppm. Levels in the ambient environment during surgical cases where significant smoke is being generated have been found to be as high as 10 ppm, the allowed exposure limit [8].

High levels of benzene (71 μg/m^3) have been detected near the electrocautery pencil during colorectal surgery and in the ambient air of the operating room (0.5–7.4 mg/m^3). [12]. Seven of 11 samples in the latter referenced study exceeded the National Institute of Occupational Safety and Health (NIOSH) recommended exposure limit of 0.1 mg/m^3 and the OSHA limit of 0.2 mg/m^3. However, a recent study found that systemic methemoglobin (MetHb), hydrogen cyanide, and acrylonitrile were elevated but not to toxic levels, and that benzene was not systemically detectable, calling into question the relevance of the presence of these chemicals in the OR [8].

Although electrocautery is potentially less hazardous than laser smoke as a route of disease transmission, intact virions have been shown to be present in electrocautery smoke, and their infectivity has been demonstrated [13]. In addition, the mutagenicity of electrocautery smoke has been estimated to be at least that of cigarette smoke [14], and has been further shown to vary in mutagenicity, depending on the type of tissue ablated [5, 15]. Benzene has been proposed to be highly responsible for the mutagenicity of electrocautery smoke.

Laser

Numerous chemicals have been found in the plume generated by laser tissue ablation, including benzene, formaldehyde, acrolein, CO, and hydrogen cyanide. These chemicals have been found in the smoke plume from both carbon dioxide and Nd:YAG laser interaction, even at very low power densities [16]. Cellular clumps and erythrocytes have also been found, suggesting the plume's infectious potential with lower irradiance levels producing more viable particles [17].

To support the theory of potential infectivity, intact strands of human papillomavirus DNA have been isolated from carbon dioxide laser plume during treatment of plantar warts [18, 19] and in laser smoke from recurrent respiratory papillomatosis [20]. Viable bacteriophage has also been demonstrated to be present in laser plume [21, 22]. The average size of particles carrying viable bacteriophage was determined to be quite large, with a mean aerodynamic diameter of 7–55 μm [23]. Whole intact virions have also been found and their infectivity demonstrated [13].

In addition to viruses and virus particles, bacteria have been cultured from laser plume in two in vitro experiments [24, 25]. A recent and more elaborate study clearly demonstrated the presence of infectious viral genes, infectious viruses, and viable cells [26]. Less infectivity has been found further from the point of production [27], and in general, the smoke generated by laser tissue ablation most likely carries more infectious potential than electrocautery [13].

Concern for the transmission of HIV infection led to a study that identified HIV DNA in laser smoke and demonstrated transmission of infection to cultured cells [28]. This infection lasted 14 days but was not present at 28 days, suggesting that the DNA had been altered in a way that prevented its propagation after infection.

Laser smoke has also been demonstrated to be cytotoxic, genotoxic, mutagenic, and clastogenic, and its mutagenicity has been estimated to be at least that of cigarette smoke and dependent on the type of tissue pyrolyzed [14].

Ultrasonic (harmonic) scalpel

Large quantities of cellular debris ($>1 \times 10^7$ particles/ml) were found in the plume generated by an ultrasonic scalpel and were approximated to be one-fourth the amount of particle concentration when compared to the plume generated by dissection of a similar amount of tissue with electrocautery [3]. Concentrations of liquid (blood or serum) aerosol were produced in a directional spray pattern when either the hook or the ball tip were used and were detected up to 40 cm from the point of production [3]. In addition, fatty tissue was found to generate 17–23 times more particulate matter than lean tissue.

The ultrasonic scalpel is said by the manufacturer to produce a vapor, not smoke, and the process has been described as low-temperature vaporization [29]. This is concerning because cool aerosols in general have a higher chance of carrying infectious and viable material than do higher temperature aerosols [30]. One study indicated that the particles created by the ultrasonic (harmonic) scalpel are composed of tissue, blood, and blood byproducts [3]. Another study noted that very few morphologically intact and no viable cells were found [31]. It is clear that this aerosol has not been well studied and no consensus exists regarding its composition.

Viable cells

The presence of viable cells in surgical smoke is controversial. This issue is of concern because of the potential for viable aerosolized cancer cells to seed distant sites such as trocar incisions leading to port-site metastases through a method known as the chimney effect. Although some studies have failed to show the presence of aerosolized cells in the peritoneal cavity during routine laparoscopic surgery [32], others have demonstrated the presence of cell-sized fragments [33], morphologically intact but nonviable cells [34], and viable cells in surgical smoke [26, 35, 36]. A 1999 study in which a more sensitive method of cell viability detection was used, a tetrazolium mitochondrial viability assay instead of the tryphan blue assay used in previous studies definitively showed the presence of viable cells in laser and electrocautery smoke [37]. The significance of the presence of these cells is not known. The presence of viable cells in the plume generated by the ultrasonic (harmonic) scalpel has not been formally investigated.

Potential hazards

Surgical smoke and aerosols are potentially dangerous to both OR personnel and patients. The potential risks to OR personnel include pulmonary irritation and inflammation, transmission of infection, and genotoxicity. The potential dangers to patients occur primarily during laparoscopic procedures in which surgical smoke is concentrated in the peritoneal cavity. These potential dangers include CO toxicity, port-site metastases from cancer spread through aerosolized cells, and toxicity to the peritoneal compartment and its contents. Intraperitoneal smoke also impairs visualization of the surgical field. What is the evidence for these potential dangers and to what degree are these potential dangers a reality?

Respiratory irritation

Many of the by-products resulting from pyrolysis of tissue are respiratory irritants [38]. It has been clearly shown that laboratory rats develop pulmonary congestion and lung abnormalities when exposed to a relatively large quantity of surgical smoke [39]. Specifically, it has been shown that surgical smoke can induce acute and chronic inflammatory changes, including alveolar congestion, interstitial pneumonia, bronchiolitis, and emphysematous changes in the respiratory tract [40, 41].

A study by the NIOSH evaluated the air that OR personnel were exposed to during laser procedures and found detectable levels of ethanol, isopropanol, anthracene, formaldehyde, cyanide, and airborne mutagenic particles. This study concluded that the level of formaldehyde present in the ambient environment would "irritate sensitive individuals" when a large amount of smoke is produced in a short period of time, and that mutagenic airborne particles are produced and it is not known what risks this poses to OR personnel [42].

In a study performed during reduction mammoplasty, concentrations of airborne particles in the OR around personnel ranged from 0.4 to 9.4 mg/m^3 of air. These levels were slightly below the allowable levels for nuisance dust evaluation criteria from OSHA (15 mg/m^3) and the American Conference of Governmental Industrial Hygienists (10 mg/m^3) [43]. However, these evaluation criteria may not apply to surgical smoke because nuisance dust is assumed to be inert. Additionally, it was found that laser vaporization of more than 3 g of tissue would produce enough acrolein and polycyclic aromatic hydrocarbons to exceed OSHA limits for these chemicals in 1 m^3 of air.

Transmission of infection

Although the possibility of disease transmission through surgical smoke exists, actual documented cases of pathogen transmission are rare. However, one case has essentially been proven. This case involved a surgeon who contracted laryngeal papillomatosis after treating anogenital condyloma with a laser. Human papillomavirus (HPV) types 6 and 11, the same types seen in anogenital papillomatosis, were found on this individual's larynx, and there was no other possible way his larynx could have come into contact with the virus [44]. The rarity of documented cases illustrates the difficulty in showing outcome effects. However, other anecdotal reports of verrucae developing on unusual sites, such as the anterior nares of laser operators, have been reported [45] and strongly suggest that transmission is occurring. This study found that the overall rate of wart prevalence among surgeons at the Mayo Clinic who treated warts with lasers was not elevated among this group compared to the general population, but that 13% (4 of 31) had warts of the nasopharynx, an area of infection uncommon in the general population [46]. An earlier study showed a transmission rate of 3.2%. Some of the infections most likely were due to patient-to-doctor contact, but none of the infections were manifest on the buccal mucosa or larynx, suggesting that direct contact was the route of transmission [47].

Genotoxicity

Smoke has been shown to be mutagenic and therefore genotoxic [5, 14, 15]. The specific method of genotoxicity is most likely multifactorial and may include chemical and biologic modalities. Certain HPV types that preferentially infect the genital region have been found in a majority of cervical carcinomas and in a few oral and laryngeal malignancies, suggesting that HPV DNA exposure is a risk factor [48–50]. One study noted that partial viral or oncogene DNA sequences can pose a significant health hazard for exposed personnel since they may have transforming potential, and it demonstrated less risk further from the point of smoke production [27]. As stated previously, it has been proposed that benzene is responsible for the mutagenicity of electrocautery smoke.

Carbon monoxide in the peritoneal cavity

CO is one of the greatest constituents of surgical smoke. Exposure to CO can cause a plethora of signs and symptoms, including 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 [51, 52].

Although there are no known safety limits of intraperitoneal CO, the EPA's maximum allowable 1-h exposure limit to ambient CO is 35 ppm, with a ceiling concentration of 200 ppm [53]. OSHA's maximum allowable exposure of ambient CO is 50 ppm for 8 h of exposure and 400 ppm for 15 min [54]. Elevated levels of intraperitoneal and systemic COHb due to peritoneal absorption of CO during routine laparoscopic cholecystectomy have been found [55]. Absolute levels of intraperitoneal CO in this study were found to increase from an average of 4.7 ppm to an average of 326 ppm and to peak levels of 686 ppm at gallbladder takedown.

COHb levels were found to increase from 0.7 ± 0.6% to 1.2 ± 0.7%. No hemodynamic changes were seen.

Other studies have further examined the issue of COHb increase due to peritoneal absorption of CO during laparoscopic surgery. The EPA has set the goal of maintaining nonsmokers' COHb below 2% [54]. Levels of 2–4% have been found to significantly decrease the time of onset of angina in persons with coronary artery disease [56, 57] and to decrease behavioral performance [58]. When surgical smoke is not evacuated during laparoscopic procedures, an increase in MetHb and COHb occurs while oxygenation of tissue decreases. MetHb levels may remain above normal in the blood stream for up to 6 h after a procedure, and these changes make pulse oximetry inaccurate [59]. Levels in one study were found to be higher than the generally accepted human threshold tolerance level of 2% [51].

One study examined whether CO exposure contributed to postoperative complaints of headaches, dizziness, and nausea—symptoms often attributed to anesthesia. This study suggested that there might be a causative effect, although no correlation between peak levels of intraabdominal CO and the presence and severity of postoperative symptoms was found [60].

Another study found that aggressive smoke evacuation and aggressive ventilation with high oxygen concentrations can offset the increase in COHb levels [61]. In this study, smoke was rapidly evacuated and two insufflators were used to maintain pneumoperitoneum. Another study revealed that the surgeon's exposure to CO by the evacuation of smoke through laparoscopic ports was negligible when gas was evacuated into the OR [60]. However, in this study only in 3 of 21 cases was a cannula opened to allow smoke to enter the operating room.

Toxicity to contents of the peritoneal cavity

The chemical components of surgical smoke may have subtle undesirable effects on the contents of the peritoneal cavity (i.e., intraabdominal macrophages). This subject has only recently been investigated. A recent study found that electrosurgery in a CO_2 environment produces smoke that is cytotoxic, which may have sublethal effects on cellular components of the immune system in the peritoneal cavity and systemically [62]. This may be significant when dealing with intraabdominal infection and in cancer in which intraabdominal immunity may play a role in fighting infectious organisms and/or malignancy.

The chimney effect

In the chimney effect, cancer cells are aerosolized during laparoscopic surgery and can leak out from around the cannula during a procedure and implant in the subcutaneous tissue. The localized inflammation from the trauma induced by the cannula and trocar insertion increases the potential for a tumor cell to implant. This phenomenon was first suggested in 1995 in a letter to the *British Journal of Surgery* [63]. This phenomenon was further elucidated the following year in a study that suggested that the presence of a pneumoperitoneum creates a pressure gradient with a subsequent outflow of gas and floating tumor cells through the port wounds, creating a chimney effect that does not occur in a standard wound [64].

Earlier studies suggested that the pneumoperitoneum might play an important role in the evolution of port-site metastases via collection of tumor cells in port sites through a mechanism of cell aerosolization [65]. A 1998 study provided evidence supporting the chimney effect. This study showed that tumor cell presence was increased where leakage was induced [66]. In support of the chimney effect hypothesis, a 1995 case report noted that a port-site metastases occurred in a wound separate from the one used to extract a carcinoma of the cecum [67]. Other studies call into question the chimney effect hypothesis and suggest other methods of port-site tumor cell implantation [68]. Results of animal experiments regarding the chimney effect are controversial, and results of small human studies do not support the hypothesis [69].

Effectiveness of surgical masks

Surgical masks have not been shown to provide adequate protection in filtering smoke, though they are good at capturing larger sized particles, generally 5 μm and larger [70–72]. Different surgical masks perform very differently, and poor fit can seriously compromise filter performance [73]. Some surgical masks have been shown to have a filter efficiency of 97% against particles averaging 1 μm in diameter; whereas penetration of particles up to 9 μm (0.1–13% penetration) has been demonstrated in other masks [74]. One study demonstrated that a surgical mask was able to prevent the passage of infectious material to target cells [13]. These findings demonstrate that masks most likely do act as a protective barrier but cannot be relied on to be completely protective. The degree to which they protect individuals from surgical smoke is not known and varies depending the filtering efficiency of the mask.

Recommendations by authoritative and national organizations

Occupational Safety and Health Administration

OSHA estimates that 500,000 workers are exposed to laser and electrocautery smoke each year. It advises that employers should be aware of this emerging problem, and that employees should be aware of the hazards of surgical smoke. OSHA has no standards specific to laser and/or electrosurgery plume. It does cite general respiratory protection standards and acknowledges that surgical masks do not qualify as respiratory protection for medical employees [75].

OSHA does not specifically require the use of smoke evacuation and filtering systems. It does regulate staff exposure to a wide range of substances (e.g., benzene, formaldehyde, hydrogen cyanide) that are found within the surgical smoke plume, and has established permissible exposure limits for these substances.

National Institute of Occupational Safety and Health

NIOSH acknowledges the dangers of surgical smoke and recommends that smoke evacuation systems be used where high concentrations of smoke and aerosols are generated. It specifically cites one of its investigations and bases its recommendations on the finding of mutagenicity of the airborne compounds collected during its evaluation and the acute health effects reported by OR personnel [42, 43]. NIOSH also recommends systems with a capture velocity of 100–150 feet per minute and that the nozzle inlet be kept 2 in. from where the plume is generated. It also states that room suction systems are not as effective and recommends that if room suction systems are used proper filters be installed and disposed of properly [76, 77].

American National Standards Institute

The official statement from the American National Standards Institute (ANSI) is somewhat confusing. It acknowledges the dangers of laser-generated airborne contaminants (LGACs), and states that electrosurgery devices create the same type of airborne contaminants and that they should all be evacuated from the surgical site [78]. ANSI states that in certain laser operations, "localized exhaust ventilation" or smoke evacuators should be used. It is not clear what methods are recommended when ANSI states "contaminants should all be evacuated" or to what "localized exhaust ventilation" refers.

Association of Operating Room Nurses

The Association of Operating Room Nurses is more specific in its recommendations. It recommends the use of smoke evacuation systems whenever smoke is generated. It also specifically cites the risk of viral contamination during laser vaporization procedures [79–81].

What can be done to minimize exposure?

Open surgery

OR personnel can do some simple things to avoid surgical smoke. They can avoid breathing in smoke plumes by moving or turning away when a large plume is present and ensure that masks are tied securely and do not have large areas of peripheral leakage. Higher quality filter masks or double masking can also be employed. Another maneuver is to place the suction device near the electrocautery blade (1–2 in.) when smoke is being produced. The effectiveness of these steps is not known, but they intuitively make sense.

Smoke evacuation systems can also be utilized. Numerous smoke evacuation systems are available for open surgery and have been independently evaluated [82, 83]. However, in general, these systems have been criticized for being noisy, expensive, annoying, and cumbersome. Newer systems have shown improvement, but they have not been widely accepted, most likely because of their previously established poor reputation.

Laparoscopic surgery

Two issues exist regarding surgical smoke in laparoscopic surgery. The first concerns smoke that is generated and present in the pneumoperitoneum that both obscures the surgeon's vision and poses a potential risk to the patient. The second pertains to the smoke released from the cannulas into the OR that potentially poses a threat to surgeons and OR personnel.

If CO exposure to the patient is a concern, the pneumoperitoneum can be continuously vented during and after electrocautery usage to ensure the lowest possible level of CO and other toxic substances in the peritoneal cavity. This will also allow a continuous dilution of potentially viable cells from an unsuspected gallbladder cancer, for example, that in rare instances can theoretically lead to a port-site metastasis.

When smoke is released from a cannula, it is generally more concentrated than smoke generated from open surgery because it is accumulated and then released all at once in a relatively high-velocity jet in a particular direction. If this jet is pointed in the direction of the surgeon or OR personnel, they can be exposed to a high concentration of smoke. To prevent this, personnel can ensure that the jet is not pointed toward them or move away if it is printed at them. One can also place a piece of gauze over the Luer-lok valve to prevent the jet from shooting in a particular direction. Another technique is to partially open the Luer-lok valve on a cannula throughout the operation or specifically when electrocautery is used to prevent smoke buildup and rapid release. The effectiveness of these techniques has not been evaluated.

Filters are available that can be attached to the Luer-lok valve on the cannula and can be set to allow continuous ventilation and filtration of the pneumoperitoneum at a rate that does not exceed the in-flow rate of the insufflator [84]. These add-on filters have been shown to reduce operative time by practically eliminating the need to interrupt the procedure and release the accumulated smoke that obstructs the surgeon's view [85]. These filters remove most of the harmful chemicals and nearly all biologic material that might be present as well as eliminate most of the smoke's odor to protect the surgeon and OR personnel from any harmful or unpleasant effects of surgical smoke.

Summary

Although in most cases surgical smoke is not an immediate threat to the patient, surgeon, and OR personnel, it cannot be ignored. Surgeons and OR personnel should be aware of the potential risks that surgical smoke poses and utilize reasonable measures to minimize exposure and prevent adverse effects.

The following established and theoretical concerns regarding surgically generated smoke are supported by scientific data:

1. Human-to-human viral transmission can occur via laser smoke when the tissue being ablated contains a high concentration of virus, such as in cases of papilloma ablation. One case of viral transmission has essentially been proven, and a number of others have been suggested. Smoke evacuators and high-efficiency filtration masks/respirators can help prevent viral transmission.
2. Electrocautery generates CO in the peritoneal cavity that exceeds recommended ambient exposure levels and can lead to methemoglobinemia that will not be indicated by pulse oximetry. This may be significant for patients with coronary artery disease and may be a contributing factor in the development of postoperative nausea and headache after laparoscopic surgery. Ventilation with high concentrations of oxygen and continuous ventilation of the pneumoperitoneum during and after electrocautery use can attenuate the increase in CO.
3. Viable cells can be present in the electrocautery plume and may lead to port-site metastases through a method known as the chimney effect. Avoidance of port-site gas leakage, minimal tumor handling to prevent exfoliation and aerosolization of cell, and ventilation of the pneumoperitoneum through cannulas either continuously or intermittently may help to prevent port-site metastases.
4. Surgical smoke and aerosols are irritating to the lungs and have approximately the mutagenicity of cigarette smoke. Risks from exposure are cumulative, and are greater for those closer to the point of smoke production. OR personnel should decide which, if any, methods they want to utilize to minimize their exposure.
5. The risks posed by the aerosol generated from the ultrasonic (harmonic) scalpel compared to that of laser and electrocautery is not known, and may be greater due to the larger size of particles generated and because it is a cooler aerosol and therefore may contain more biologically viable particles.
6. The toxic effects of aerosols on the intraabdominal cellular immune system are not known, and may decrease this system's ability to fight intraabdominal infection and cancer.

Recommendations

Concern for fine particulate air pollution is controversial, and hard evidence of its risks is difficult to document. A recent study linked air quality to the risk of death from all causes, mainly cardiovascular and respiratory, for large populations of continuously exposed individuals [86]. Additionally, the risks of cigarette smoke, either through direct inhalation or through second-hand smoke, are well documented. The dangers and potential dangers of surgical smoke have been known for approximately two decades. However, few precautionary steps have been taken with regard to surgical smoke in most ORs because many of the effects are subtle, not immediate, and have not been adequately defined.

Every year, more laparoscopic procedures are being performed for a wider range of indications and on an increasingly sicker patient population. In addition, new surgical power equipment, such as the harmonic scalpel, is being employed for an ever-enlarging spectrum of situations. Surgeons need to carefully assess the dangers and potential dangers of surgical smoke, educate doctors and staff about these dangers, adjust techniques where reasonable, and make all reasonable efforts to protect themselves, their patients, and the OR staff.

To further define when precautions are indicated, additional research is necessary. This research must take into consideration the variability among test subjects, including whether subjects have any preexisting medical conditions or are hypersensitive to any of the smoke's constituents. However, this research would be difficult to perform because most effects would become apparent only after large numbers of individuals were studied over a long period of time. Considering the variability in the amount and time of exposure among surgeons and OR personnel, safe exposure limits would most likely need to be set. Defining such limits would require that each individual's actual chemical exposures be determined and take into account an individual's daily, weekly, and lifetime exposure potential.

Smoke may have additional effects during laparoscopic surgery that have not yet been identified. Creation of the pneumoperitoneum during laparoscopic surgery is known to suppress cell-mediated intraabdominal immunity. This suppression has been theorized to result from direct pressure effects leading to decreased local blood flow and/or from CO_2 toxicity. Local toxins produced from electrocautery or other energy sources may also contribute to this suppression. If this can be shown, continuous ventilation of these toxins from the pneumoperitoneum may be warranted.

The following recommendations seem reasonable:

1. Surgeons and OR personnel should minimize their smoke exposure when feasible to prevent long-term effects of respiratory irritation and increased cumulative cancer risk. This can be done by avoiding surgical smoke, sucking it with a sucker near the point of generation, utilizing add-on cannula filters during laparoscopic cases, or by the use of a smoke evacuation system.
2. Surgeons and OR personnel should do all that is possible to protect themselves when smoke is generated from tissue with a high viral concentration, such as during ablation of papillomas to prevent transmission of viral diseases. This includes using smoke evacuators and high-filtration masks.

3. During laparoscopic operations, surgeons should ventilate the pneumoperitoneum either continuously or intermittently and aggressively when smoke is produced from electrocautery and laser to reduce intraabdominal levels of CO and other toxins.
4. During laparoscopic cases, add-on cannula filters should be employed and perhaps incorporated into future generation of cannulas.
5. Research is needed to determine the potential dangers of the aerosol generated by the ultrasonic (harmonic) scalpel to assess its ability to spread pathogens and cells and create toxins.
6. Additional research should be performed to determine when smoke evacuation systems need to be used. For certain operations such as reduction mammoplasty, in which a significant amount of smoke is generated, a smoke evacuation system should be used.
7. Additional outcome research on the actual risks of surgical smoke should be performed.

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