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REVIEW

Surgical smoke and infection control

E. Alp[a,b], D. Bijl[c], R.P. Bleichrodt[d], B. Hansson[d], A. Voss[a,e,*]

[a]*Nijmegen University Centre of Infections Diseases, Radboud University Medical Centre, Nijmegen, The Netherlands*
[b]*Department of Infectious Diseases, Faculty of Medicine, Erciyes University, Kayseri, Turkey*
[c]*Department of Central Sterilization, University Medical Centre St Radboud, Nijmegen, The Netherlands*
[d]*Division of Abdominal Surgery, Department of Surgery, University Medical Centre St Radboud, Nijmegen, The Netherlands*
[e]*Medical Microbiology and Infectious Diseases, Canisius-Wilhelmina Hospital, Nijmegen, The Netherlands*

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Summary Gaseous byproducts produced during electrocautery, laser surgery or the use of ultrasonic scalpels are usually referred to as 'surgical smoke'. This smoke, produced with or without a heating process, contains bio-aerosols with viable and non-viable cellular material that subsequently poses a risk of infection (human immunodeficiency virus, hepatitis B virus, human papillomavirus) and causes irritation to the lungs leading to acute and chronic inflammatory changes. Furthermore, cytotoxic, genotoxic and mutagenic effects have been demonstrated. The American Occupational Safety and Health Administration have estimated that 500 000 workers are exposed to laser and electrosurgical smoke each year. The use of standard surgical masks alone does not provide adequate protection from surgical smoke. While higher quality filter masks and/or double masking may increase the filtration capability, a smoke evacuation device or filter placed near (2–5 cm) the electrocautery blade or on endoscope valves offers additional (and necessary) safety for operating personnel and patients.

Introduction

The term 'smoke' is used to describe any gaseous byproduct containing bio-aerosols, including viable and non-viable cellular material. In the medical literature, the terms 'smoke', 'plume' and, sometimes, 'aerosol' are used to describe the product of laser tissue ablation and electrocautery. The product of ultrasonic scalpels is frequently referred to as 'plume', 'aerosol' and 'vapour'.

The generation of surgical smoke by electrocautery and laser systems has the same mechanism. During the procedure (cut, coagulate, vaporize or ablate tissue), the target cells are heated to the

* Corresponding author. Address: Medical Microbiology and Infectious Diseases, Canisius-Wilhelmina Hospital, P.O. Box 9015, 6500 GS Nijmegen, The Netherlands. Tel.: +31 24 3657515; fax: +31 24 3657516.
E-mail address: a.voss@cwz.nl

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point of boiling, causing the membranes to rupture and disperse fine particles into the air or pneumoperitoneum. The qualities of surgical smoke produced by these two methods are very similar. During the use of ultrasonic scalpels, aerosols are produced without a heating (burning) process. This process is generally referred to as 'low-temperature vaporization'. On the whole, this low-temperature vapour has a higher chance of carrying viable and infectious particles than higher temperature aerosols.

The mean aerodynamic size of particles generated varies greatly depending on the energy method used. Electrocautery creates particles with the smallest mean aerodynamic size (<0.1 μm), laser tissue ablation creates larger particles (~ 0.3 μm), and the largest particles are generated by use of an ultrasonic scalpel (0.35–6.5 μm). These particles travel greater distances from their point of production (up to 100 cm). The nature of small particles presents a hazard to patients and personnel. Particles of 0.5–5.0 μm are frequently referred to as 'lung-damaging dust' since they can penetrate to the deepest regions of the lung. Surgical smoke can induce acute and chronic inflammatory changes, including alveolar congestion, interstitial pneumonia, bronchiolitis and emphysematous changes in the respiratory tract (Table I).

Furthermore, 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 extent of the surgery (cutting, coagulation or ablating) are other factors influencing the quantity and quality of the surgical smoke.

Surgical smoke has also been demonstrated to be cytotoxic, genotoxic and mutagenic.[1]

Table I Risks of surgical smoke

Acute and chronic inflammatory changes in respiratory tract (emphysema, asthma, chronic bronchitis)
Hypoxia/dizziness
Eye irritation
Nausea/vomiting
Headache
Sneezing
Weakness
Lightheadedness
Carcinoma
Dermatitis
Cardiovascular dysfunction
Throat irritation
Lacrimation
Colic
Anxiety
Anaemia
Leukaemia
Nasopharyngeal lesions
Human immunodeficiency virus
Hepatitis

Potential health risks associated with surgical smoke

Electrosurgery

Electrosurgery is one of the most commonly used energy systems in laparoscopic surgery. Two major categories of potential complications related to electrosurgery are mechanical trauma and electrothermal injury. Electrothermal injuries and the burning of proteins and lipids produces a noxious odour noticeable in the operating room (OR). In addition to possible long-term effects, these chemicals may cause headaches, irritation and soreness of the eyes, nose and throat.[2] The American Occupational Safety and Health Administration (OSHA, www.osha.gov) has set permissible exposure limits (PELs) for workers. The health effects associated with these chemicals represent exposure in excess of these PELs. The purpose of PELs is to prevent these health effects from occurring and to provide a safe working environment for people potentially exposed to these chemicals.

While hydrocarbons, phenols, nitriles and fatty acids are the most prominent chemicals found in electrocautery smoke, acrylonitrile and carbon monoxide (CO) are of most concern.[1]

Acrylonitrile has toxic effects due to the formation of cyanide. Short-term exposure 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.

CO is of particular concern in laparoscopic procedures and is readily absorbed from the peritoneum into the bloodstream, creating a route for systemic intoxication. The combination of CO and haemoglobin forms carboxyhaemoglobin (HbCO) and methaemoglobin (MetHb). Excessive accumulations of HbCO and MetHb cause hypoxic stress in healthy individuals as a result of the reduced oxygen-carrying capacity of the blood. In patients with cardiovascular disease, such stress can further impair cardiovascular function.[1,3]

Hydrogen cyanide is a colourless, toxic gas that may cause headache, weakness, throat irritation, vomiting, dyspnoea, lacrimation, colic and nervousness after absorption through skin and lungs.

Benzene causes irritation in eyes, nose and respiratory tract, headache, dizziness and nausea. Long-term exposure even at relatively low concentrations may result in various blood disorders, ranging from anaemia to leukaemia. Many blood disorders associated with benzene exposure may occur without symptoms.

The mutagenic effect created by thermal destruction of 1 g of tissue is equivalent to that of three or six cigarettes for laser and electrocautery smoke, respectively.[1] A recent study demonstrated that electrosurgical smoke, produced in a helium environment, reduced the clonogenicity of MCF-7 human breast carcinoma cells in a dose-dependent manner and concluded that electrosurgical smoke is cytotoxic.[4]

In one study, pellets of B16-F0 mouse melanoma cells were cauterized and the plume was collected in culture medium. Intact melanoma cells were identified in the culture media.[5] The authors concluded that viable cancer cells can be disseminated in the abdominal cavity and can lead to port-site metastasis in laparoscopic surgery. However, others concluded that malignant cells only aerosolize during laparascopy in the presence of carcinomatosis and that it is unlikely that tumour aerosolization contributes significantly to port-site metastasis.[6,7]

In recent years, electrocautery has been commonly used for the treatment of genital warts, caused by human papillomavirus (HPV), and cervical neoplasia in patients infected with human immunodeficiency virus (HIV). 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.[1] Therefore, genital warts must not be treated by electrosurgery. Simple excision is the therapy of choice.

Laser

There has been an increasing awareness of the potential health risk of laser-generated plumes. Many laser systems, on impact with targeted tissue, produce a plume of smoke containing debris and vapour, which is released into the surrounding area. Chemicals that have been found in the plume generated by laser tissue ablation are benzene, formaldehyde, acrolein, CO and hydrogen cyanide. These chemicals have been found in the smoke plume from both carbon dioxide (CO_2) and Nd:YAG lasers.[1]

Furthermore, viable particles (i.e. cellular elements and erythrocytes) have been found in plumes, suggesting their infectious potential. Over recent years, medical professionals have become aware of the dangerous exposure to viruses. Numerous studies have been conducted to examine virus viability in electrocautery and laser smoke.[8,9] In a tissue culture study using a CO_2 laser, proviral HIV DNA was recovered from the suction tubing used to remove the plume.[10] In another study, bovine papillomavirus DNA was detected in the laser aerosol.[11] In a survey, the incidence of nasopharyngeal lesions among CO_2 laser surgeons was found to be higher than in a control group, indicating that CO_2 laser surgeons are at increased risk of acquiring nasopharyngeal warts through inhalation of laser plumes.[12] A case report linked the laryngeal papillomatosis in an Nd:YAG laser surgeon to virus particles in the laser plume from one of his patients.[13] Since HPV and HIV can be detected in laser plumes, it is probable that other viruses, such as hepatitis viruses, may also be liberated in plumes during laser use.[14]

Ultrasonic scalpel

Large quantities of cellular debris ($>1\times10^7$ particles/mL) are found in plumes generated by ultrasonic scalpels. The particles created by the ultrasonic scalpel are composed of tissue, blood and blood byproducts. Unfortunately, those aerosols have not been well studied and no agreement exists about their exact composition. Whether the risk posed by aerosols generated by the use of ultrasonic scalpels is comparable with that of laser and electrocautery is not known. It might be greater due to the larger size of particles generated and because its low temperature vapour may contain more viable particles.[1] Research is needed to determine the potential dangers of aerosols generated by ultrasonic scalpels to assess their ability to spread pathogens and cells and to form toxins.

Recommendations by national organizations

OSHA estimates that 500 000 workers are exposed to laser and electrosurgical smoke each year, including surgeons, nurses, anaesthesiologists and surgical technologists. Surgical masks are good at capturing larger sized particles, generally 5 μm and larger, but they do not provide adequate protection in filtering smoke. Various studies demonstrated that specially designed masks (respirators) are still insufficient barriers. Furthermore, leakage of the mask's seal to the face is another source of possible penetration. No studies have measured the effectiveness of these respirators. The degree to which they protect individuals from surgical smoke is not known and varies depending on the filtering efficiency of the different respirators. As bloodborne pathogens have been identified in surgical smoke, occupational health regulations should be applied. Employers should provide appropriate personal protective equipment such as, but not limited to, gloves, gowns, laboratory coats, face shields or masks, and eye protection. Personal protective equipment will only be considered to be 'appropriate' if does not permit blood or other potentially infectious materials to pass through to or reach the employee's work clothes, street clothes, undergarments, skin, eyes, mouth or other mucous membranes under normal conditions of use and for the duration of time for which the protective equipment will be used.

OSHA does not specifically require the use of smoke evacuation and filtering systems. However, it does regulate staff exposure to a wide range of substances that are found within surgical smoke plumes, and has established PELs for these substances.

Other organizations recommend smoke evacuation systems where high concentrations of smoke and aerosols are generated. Systems with a capture velocity of 30–40 m/min are recommended, and the needle inlet should be kept 5 cm from where the plume is generated. Proper filters have to be installed and disposed of properly when room suction systems are used because room suction systems are less effective.[15–18]

Recommendations for infection control

During open surgery, there are various ways for OR personnel to avoid surgical smoke, e.g. by moving or turning away from large plumes and thereby avoiding inhalation. They can engage higher quality filter masks or double masking. A simple smoke evacuation system suction device can be placed near the electrocautery blade (2–3 cm) when smoke is produced; if placed too far away, only 50% of the smoke will be evacuated.[1,19] The three components of an efficient evacuation system should be: a capture device that does not interfere with the surgeon's activities; a vacuum source which has strong enough suction to remove the smoke properly; and a filtration system that is capable of filtering the smoke and making the environment safer.[20]

During endoscopic surgery, a chimney effect may cause a jet stream through the trocards towards the operating personnel. Moreover, smoke during endoscopic procedures is accumulated and then released all at once in a relatively high-velocity jet in a particular direction. Consequently, the surgeon or OR personnel can be exposed to a high concentration of cells, burns and infectious particles. To avoid this, personnel should ensure that the jet is not pointed towards them. By partially opening the Luer-lok valve on a cannula throughout the operation, especially when electrocautery is used, it might be possible to prevent smoke buildup and rapid release.

Recently, filters have become available that can be attached to the Luer-lock 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 inflow rate of the insufflator. 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. These filters remove most of the harmful chemicals and nearly all biological material that might be present, and eliminate most of the smoke's odour.[1]

Conclusion

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. Smoke evacuators and high-efficiency filtration masks/respirators can help to prevent the transmission of infectious agents.

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