

CPD

Surgical plume in dermatology: an insidious and often overlooked hazard

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doi:10.1111/ced.14350

Abstract

Dermatologists performing surgical procedures face occupational and health hazards when exposed to surgical plume released during electrosurgical and ablative laser procedures. These hazardous fumes have toxic, infectious and carcinogenic effects. Understanding this risk is of particular importance during the COVID-19 pandemic as the understanding of the transmissibility and infectious nature of the virus is still evolving rapidly. In this article, we present the hazards from laser and surgical plumes, and discuss possible preventative measures aimed at reducing these risks.

Introduction

Dermatologists frequently undertake procedures using electrosurgical and ablative laser devices, generating a cloud of surgical smoke known as plume, which can pose harm to both patients and staff. Surgical plume is made up of 95% water and 5% particulate matter with toxic, carcinogenic and infectious potential.¹ Despite this occupational hazard, the risks posed to dermatologists from particulate matter released in surgical plume have received little attention. We discuss the potential hazards of surgical plume and the protective measures that can be taken to mitigate these risks, which we believe are particularly important in the COVID-19 era.

Terminology and definitions

The primary hazard of surgical smoke is its propensity to cause harm following inhalation. Airborne spread

and diffusivity of particulate matter is dependent on its size, with smaller particles having greater diffusivity than larger ones. Particles < 5 µm in diameter can travel down the lower respiratory tract (including the bronchioles and alveoli) and are generally referred to as 'aerosols', whereas larger particles (> 5 µm) are referred to as 'droplets' and can reach the upper respiratory tract (including the pharynx, trachea and bronchi).² The mean particle size produced in the plumes of electrosurgical and ablative laser devices (such as the CO₂ laser) is predominantly < 1 µm.^{3,4}

There is currently some confusion in the literature as the terms 'airborne' and 'aerosols' are occasionally used interchangeably. For the purposes of this article, we have adhered to the Public Health England definition of 'aerosols' as particles of < 5 µm in diameter.⁵ Electrocautery and ablative lasers generate plumes with aerosols (small particle diameter) and as such are defined as 'aerosol-generating procedures'.

Surgical plume composition

Plume from electrocautery and ablative lasers has been found to contain a range of toxic, infectious and carcinogenic components. Toxic metabolites include organic compounds and metabolites, of which hydrocarbons, phenols, nitriles and fatty acids pose

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Conflict of interest: the authors declare that they have no conflicts of interest.

Accepted for publication 5 June 2020

the most egregious risk (Table 1).⁶ Hydrogen cyanide, acetylene and 1,3-butadiene ethyl-benzene-styrene, carbon disulphide, methyl propane and toluene have also been identified in variable concentrations.^{7,8} Of note, the latter two components have been found in higher concentrations in surgical plume than in both cigarette smoke and city air.⁹ The pathogenic potential of each component upon inhalation is unknown (Fig. 1).

Hazardous components of laser plume include acetonitrile, acrolein, ammonia, benzene, ethylene and toluene¹⁰ (Table 2).

Factors affecting plume composition

Various factors affect the composition of surgical plume. These relate to the type of procedure performed, the instrument and parameters used and the tissue being treated.¹¹

The instrument and parameters used affect the nature of the particulate matter.⁵ Bipolar and ultrasonic instruments have been shown to produce less plume (measured as 'visibility') than unipolar/monopolar devices.¹²

In addition, more plume appears to be generated with greater energy settings: during tonsillectomies with monopolar electrocautery, particle concentrations were 9.5 times higher when the power was set to 20 W vs. 12 W.¹³

Tissue-related particulate composition studies have shown that thermal decomposition of adipose tissue released more aldehydes and lower concentrations of toluene in the smoke, whereas ablation of epidermal tissue produced greater levels of toluene, ethyl benzene and xylene.¹⁴

Toxic risk

Acrylonitrile is a volatile chemical that releases hydrogen cyanide and is absorbed by the skin and lungs. Short-term exposure has been linked to headaches, eye irritation, vomiting, sneezing and dizziness, while long-term exposure has been associated with cancer in humans.¹⁵ Benzene released in electrocautery plume has been linked with haematological cancers, can affect the central nervous system (CNS) and is an irritant.¹⁵ Toluene is highly pungent, may depress the CNS and can act as an irritant. Other common components of surgical plume (including ethyl benzene, xylene, styrene, formaldehyde) are variously carcinogenic, irritant, cause respiratory disease and may cause haematological problems.

Table 1 Plume composition, proven toxics infectious and carcinogenic particles in plume, and filters to reduce plume inhalation.

Electrosurgical plume components

1-Decene
1-Undecene
2-Methyl furan, 2,5-dimethyl furan
2-Methyl propanol
2-Propylene nitrile
2,3-Dihydro indene
3-Butenenitrile
3-Methyl butenal
4-methyl phenol
6-Methyl indole
Acrylonitrile
Benzaldehyde
Benzonitrile
Ethyl benzene
Ethyne benzene
Furfural
Hexadecanoic acid
Indole
Methyl pyrazine
Pyrrole
Toluene

Laser plume components

Acetonitrile
Acrolein
Ammonia
Benzene
Ethylene
Toluene

Proven toxic components

Acrylonitrile
Benzene
Hydrogen cyanide
Carcinogenic particles
Acetaldehyde acrolein
Acrylonitrile
Acrylonitrile
Benzene
Toluene

Infective particles

Hepatitis B
HIV
HPV 6, 11 and 16
Corynebacterium
Neisseria
Staphylococcus

Filters

Charcoal
FFP
HEPA
ULPA

FFP, filtering face piece; HEPA, high-efficiency particulate air; HIV, human immunodeficiency virus; HPV, human papillomavirus; ULPA, ultra-low particulate air.

Although human studies have not been reported, there is evidence from animal models that pulmonary damage (including emphysematous change) can be

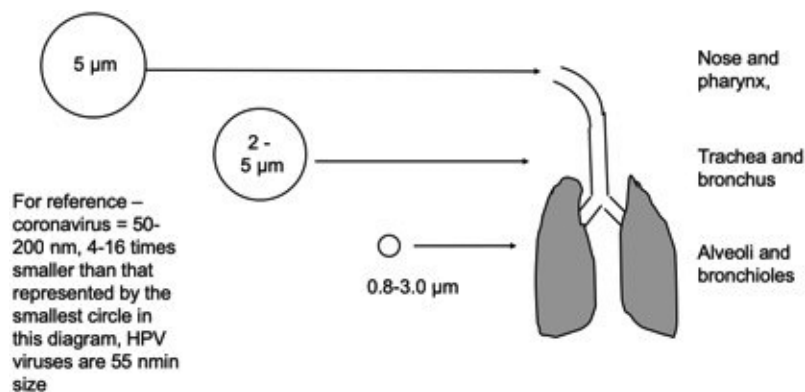


Figure 1 Particle size and anatomical deposition of particles. Adapted from Okoshi et al., 2015.⁴

Table 2 Comparison of different mask types.

Mask type	Protection against	Filtration capability	Fit test needed
Type IIR	Droplets	Varies	No
FFP2 respirators	Droplets and airborne particles	> 94%	Yes
FFP3 respirators	Droplets and airborne particles	> 99%	Yes

FFP, filtering face piece.

inflicted by exposure to plume, but can be lessened by the use of smoke evacuators.¹⁶

Carcinogenic risk

Ample evidence exists to suggest that inhalation of plumes is carcinogenic to humans, due to both the toxic metabolites and to underlying carcinogenic viruses that may be contained in the plume.

Tomita *et al.* found that the amount of smoke condensates produced from 1 g of tissue using a CO₂ laser and electrocautery was equivalent to that of three and six cigarettes, respectively.¹⁷ Another study reported that daily plume generated from monopolar electrocautery on human and porcine muscle tissue was equivalent to 27–30 cigarettes.¹⁸

The carcinogenic risk from polycyclic aromatic hydrocarbons (PAHs) generated from electrocautery plume is estimated to be 20–30 times higher than that posed by the risk from environmental pollution. A study reported the 70-year lifetime cancer risk of surgeons exposed to PAHs in electrocautery smoke was

117 times greater than that of a person exposed to the safe level of 1×10^{-6} advised by the World Health Organization.^{11,19}

Infectious risk

Surgical plume harbours viable particulate pathogens with the potential of transmission and infection. These pathogens may originate from the skin, mucocutaneous surfaces and body fluids.^{1,15} Lower-temperature plumes (such as CO₂ laser plumes) are associated with higher infectivity.²⁰

Coagulase-negative *Staphylococci* were identified in the plume of 5 of 13 patients undergoing ablative laser treatment, with 1 case each of *Corynebacterium* and *Neisseria* also reported.²¹

A study looking at concentrations of human papillomavirus (HPV) DNA from treated plantar warts in both ablative laser and electrocautery plume found the virus in 62% and 57%, respectively.²²

Another study compared the incidence of warts in CO₂ laser surgeons and population-based controls. The incidence of plantar, nasopharyngeal and genital/perianal warts was significantly greater among the CO₂ laser surgeons, suggesting that treated tissue containing HPV viruses can be inhaled and eventuate in the upper airway of operators via the laser plume.²³

The risk of viral particle inhalation is supported by two cases of laryngeal papillomatosis secondary to plume inhalation from CO₂ laser and electrocautery in healthcare professionals involved in the treatment of HPV papillomas.^{24,25} A DNA analysis of HPV subtyping in one case confirmed the identical subtypes 6 and 11 in the operator.²⁴ HPV virus particles are estimated

to be about 55 nm in diameter and their small size makes them inhalable during aerosol-generating procedures,²⁴ which is particularly concerning as they are associated with oropharyngeal cancer.

Evidence exists on the presence of blood and blood-borne viruses in surgical plume. Hepatitis B virus (HBV) has been found in 91% of surgical plumes generated by laparoscopic surgery of affected patients.^{26,27} An *in vitro* study of tissue samples infected with human immunodeficiency virus (HIV) treated with CO₂ laser found HIV antigens detectable in 3 of 12 tube segments after 1 week of culture and in 1 of 12 after 2 weeks. PCR analysis of the sterile tubing through which vaporized debris from the laser CO₂ passed was positive for proviral HIV DNA upon immediate sampling and on day 14 in culture.²⁸

Although there are no reported cases of COVID-19 transmission via surgical plumes, the small size of coronavirus virions (50–200 nm)²⁹ and their presence outside the respiratory tract in bodily fluids (including in blood, peritoneal fluid and faeces)^{30,31} and their high transmissibility makes the presence of the virus in inhaled surgical plume highly plausible.³² Decreasing the volume of plume, with a consequent reduction in the risk of viable viral particles present, can be attempted by using lower power settings and considering the use of bipolar cautery. Given the fact that ablative lasers generate greater concentrations of particles of greater infectious potential, it is highly recommended that ablative lasers are only used in patients confirmed as COVID-19free, with the maximum protection used such as filtering face piece (FFP)3 masks with appropriate filters, and plume extraction.^{33,34}

Protective measures

Appropriate precautions for surgical plume include appropriate masks and eyewear, smoke evacuation, ventilation and suction.

Standard surgical masks do not adequately filter particulate matter < 5 µm (including most toxic metabolites and viral particles) from inhalation. However, they might impede larger droplets or splashes perioperatively.³² If applied correctly, FFP2 and FFP3 masks can filter up to 94% and 99%, respectively, of particles from entering the respiratory tract.³⁵ Masks should be properly fitted to reduce air leaks, covering both the nose and mouth, and staff should have annual fit testing. Protective eyewear should be encouraged to prevent ocular irritation and possible contamination.³⁶

General ventilation dilutes the contaminated air before levels reach hazardous concentrations and is recommended.³⁷

Smoke evacuation is necessary to trap contaminants close to the source and – in addition to aiding in clear visibility – can prevent the diffusion of particulate matter to the atmosphere, thus reducing exposure to both the patient and staff. In a study investigating the plume released during laser hair removal, when the smoke extractor was turned off for 30 s the particulate matter content increased by 26 times compared with baseline environmental levels.³⁷ Although laser hair removal is not an ablative procedure, plume is generated from hair shaft vaporization.

The most common form of plume evacuation is through dispersion, in which there is suctioning of the generated smoke into a central vacuum.¹¹ Other techniques include smoke evacuation using filters. These can be attached to suction devices to prevent components of the plume diffusing into the environment. Evacuators can be built into electrocautery devices. Filters tend to use both suction and mechanical filtering, such as a combination of high-efficiency particulate air (HEPA) filters, which can filter particles ≥ 0.3 µm in size, and ultra-low particulate air (ULPA) filters, which can filter 99.99% of particles ≥ 0.12 µm.¹¹ Filters must be replaced frequently, and care is needed to prevent the release of any particulate matter that has accumulated, and to prevent the growth of microorganisms.¹¹

The UK Health and Safety Executive recommend routine use of extractors for surgical plume.³⁸ However, only 66% of UK plastic surgery units were reported to use smoke extractor devices, highlighting the potential occupational hazards.¹⁸

Conclusion

Surgical plumes potentially have toxic, carcinogenic and infectious capacity. Surgical masks confer little protection to the respiratory tract against aerosols generated during surgery or CO₂ laser procedures. To reduce the quantity of plume generated, operators should consider using bipolar (as opposed to unipolar or monopolar) cautery at the lowest power settings. Mechanisms to remove the generated plumes through vacuum extraction should be implemented, as well as the use of appropriate personal protective equipment.

Learning points

- Surgical plume is a risk that dermatologists may face when carrying out common surgical procedures such as electrocautery and laser.
- The potential infectious risk of surgical plumes including reports of HPV transmission.
- The risk of carcinogenicity of surgical smoke caused by its toxic components.
- Bipolar cautery and lower power settings generate lower concentrations of surgical plume.
- Viruses and bacteria can be transmitted via surgical plume.
- There are no reports of COVID-19 transmission via surgical plume; however, this is physically possible and may represent a hazard to operators.
- There remains a need for plume extraction and appropriate masks during plume-generating procedures.

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CPD questions

Learning objective

To gain up-to-date knowledge on the hazards associated with surgical plume.

Question 1

Which of these infectious particles has not currently been found to be transmissible by studies investigating surgical plume?

- (a) Human papillomavirus 6.
- (b) *Staphylococcus*.
- (c) *Corynebacterium*.
- (d) *Neisseria*.
- (e) COVID-19.

Question 2

What is the safe level for polycyclic aromatic hydrocarbons, according to the World Health Organization (WHO)?

- (a) 1×10^{-6}
- (b) 1×10^{-9}
- (c) 1×10^{-12}
- (d) 1×10^6
- (e) 1×10^9

Question 3

Infection with human papillomavirus can cause the development of which of these cancers?

- (a) Merkel cell carcinoma.
- (b) Oropharyngeal cancer.
- (c) Malignant melanoma.
- (d) Burkitt lymphoma.
- (e) Hodgkin lymphoma.

Question 4

Which of the following is not used as a preventative technique to reduce the hazard posed by surgical plume?

- (a) N95 surgical mask.
- (b) Ultra-low particulate air filters.
- (c) Dynamic pressure ventilation.
- (d) High-efficiency particulate air filters.

Question 5

Which of these substances is a component of the surgical plume and can be broken down to release hydrogen cyanide?

- (a) Acrylonitrile.

- (b) Benzene.
- (c) Toluene.
- (d) Benzaldehyde.
- (e) Acetonitrile.

Instructions for answering questions

This learning activity is freely available online at <http://www.wileyhealthlearning.com/ced>

Users are encouraged to

- Read the article in print or online, paying particular attention to the learning points and any author conflict of interest disclosures

- Reflect on the article
- Register or login online at <http://www.wileyhealthlearning.com/ced> and answer the CPD questions
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