ELSEVIER Review Article

Surgical Smoke

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Surgical smoke is the gaseous by-product formed during surgical procedures. Most surgeons, operating theatre staff and administrators are unaware of its potential health risks. Surgical smoke is produced by various surgical instruments including those used in electrocautery, lasers, ultrasonic scalpels, high speed drills, burrs and saws. The potential risks include carbon monoxide toxicity to the patient undergoing a laparoscopic operation, pulmonary fibrosis induced by non-viable particles, and transmission of infectious diseases like human papilloma virus. Cytotoxicity and mutagenicity are other concerns. Minimisation of the production of surgical smoke and modification of any evacuation systems are possible solutions. In general, a surgical mask can provide more than 90% protection to exposure to surgical smoke; however, in most circumstances it cannot provide air-tight protection to the user. An at least N95 grade or equivalent respirator offers the best protection against surgical smoke, but whether such protection is necessary is currently unknown. [*Asian J Surg* 2009;32(4):253–7]

Key Words: aerosol, cautery, respirator, toxicity

Introduction

"Surgical smoke" is the gaseous by-product produced during surgical procedures. It is also known as aerosols, cautery smoke, diathermy plume, plume or smoke plume. Most surgeons, operating theatre staff, and administrators are unaware of its health risks. A recent survey in the UK revealed that only 3 of 98 surgeons used dedicated smoke extractors, although 72% of surgeons felt that inadequate precautions were taken to protect staff and patients from surgical smoke.[1]

In general, surgical smoke is produced by electrocautery devices, laser ablation, ultrasonic scalpels, high speed drills, burrs and saws as a result of disruption and vaporisation of tissue protein and fat.[2] It hinders the vision of the surgeon, produces an unpleasant odour, and releases harmful substances into the air.[3] Studies have shown that these substances could cause headaches, irritation of the eyes and other mucous membranes, and could also result in other potential long-term effects.[4,5] Epidemiological and toxicological studies have also shown that exposure to particulate air pollution is associated with adverse effects on the cardiovascular and respiratory systems as well as with increased mortality.[6–8]

This article reviews the potential hazards of surgical smoke and provides recommendations to the surgical community based on current knowledge available in the literature.

Potential Hazards

Carbon monoxide production

The production of carbon monoxide (CO) during tissue ablation is most commonly seen during diathermy application.[9] This may be a result of either incomplete combustion or the presence of carbon dioxide during laparoscopic procedures. The production of CO is enhanced by the presence of high carbon dioxide levels in the peritoneal cavity

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Table 1. Sizes of particles produced by different surgical instruments

Instrument	Size (μm)
Electrocautery	0.007–0.42
Laser	0.1–0.8
Ultrasonic scalpel	0.35–6.5

and increased intra-abdominal pressure during laparoscopic surgery. Carbon monoxide, which acts as a competitor to the oxygen molecule for haemoglobin, causes tissue hypoxia. The CO level in the patient's blood is significantly increased after a laparoscopic cholecystectomy, even in healthy non-smokers. Preventive measures include hyperventilation with a high concentration of oxygen (e.g. 50–100%), and aggressive evacuation of the surgical smoke.[10]

Non-viable particles

Particles of various sizes are produced by surgical instruments (Table 1). The smaller the particles, the further the distance they can travel in air. Smaller particles could therefore affect the non-scrubbed staff in the operating theatre. Particles that range in size from 0.5 to 5.0 μm are considered to be "lung damaging dust". They carry the risk of bronchiolitis, emphysema and pulmonary fibrosis. These pathological changes have been shown in a rat model.[11,12]

It has been shown recently that electrocautery and argon plasma coagulation induced the production of a very high number concentration (> 100,000 cm^{-3}) of particles with diameters ranging from 10 nm to 1 μm.[13] The peak concentration was confined to the immediate local surrounding of the surgical site.[13]

Viable bacteria and viruses

Of the bacterial cultures grown on specimens collected from laser plume smoke during laser procedures in 13 patients, five grew coagulase-negative *Staphylococcus*.[14] Of these five positive cultures, one also grew *Corynebacterium* and the other grew *Neisseria*.[14]

There is substantial evidence showing the presence of viable viruses in surgical smoke. A surgeon was reported to have developed laryngeal papillomatosis after neodymium: yttrium-aluminium-garnet laser treatment for a patient with anogenital condylomata due to human papillomavirus (HPV) infection. In situ DNA hybridisation of the laryngeal papilloma tissues showed that the HPV was of types 6 and 11, same as that of the patient.[15] In another study, intact viral DNA could be demonstrated in the plume collected during carbon laser therapy of papillomavirus-infected verrucae.[16] The same investigators subsequently confirmed the infectivity of the laser plume by inoculation into the skin of calves.[17] These findings support the possibility of viral transmission through surgical smoke.

Viable human immunodeficiency virus (HIV) was demonstrated in cool aerosols generated by devices like Midas Rex (Medtronic Inc, Minneapolis, MN, USA) and Stryker (Stryker Instruments, Kalamazoo, MI, USA) oscillating bone saws but not in fumes generated by electrocautery.[18] HIV DNA has also been found in surgical smoke and it remained viable for 14 days. However, its infectivity to humans is uncertain and further studies are needed.[19]

Studies have shown that smoke generated by ultrasonic scalpels has a lower temperature and is more likely to contain more infectious material than smoke of higher temperatures.[18]

Viable cells

Intact cells and blood components are aerosolised by laser, electrocautery, and ultrasonic scalpels. Potential risks include the spread of infection to health care workers, and dissemination of cancer cells. Viable melanoma cells were demonstrated by trypan blue assay and tetrazolium [3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide] (MTT) in a plume generated by electrocautery of mouse melanoma cells.[20] This may account for the well-known phenomenon of tumour recurrence in a port site remote from where a tumour was previously extracted after laparoscopic resection.[21] One of the proposed mechanisms is the "chimney effect"—the leakage of gas carrying viable cells through port sites during laparoscopic surgery.[22] It is interesting to note that ultrasonic scalpels did not produce viable cancer cells during dissection.[23]

Chemicals and cytotoxicity

Various chemical compounds (Table 2) have been isolated in surgical smoke—for example, hydrogen cyanide, benzene, hydrocarbons, nitriles, fatty acids, and phenols.[2,24–26] These compounds were responsible for the noxious odour of surgical smoke. Acrylonitrile is a colourless volatile liquid that will liberate cyanide and is easily absorbed

Table 2. Examples of chemical compounds found in surgical smoke

Hydrocarbons
- Acetylene
- Benzene
- 1-Decene
- 2,3-dihydro indene
- Ethyl benzene
- Ethynyl benzene
- Styrene
- Toluene
- 1-Undecene

Nitriles
- Acetonitrile
- Acrylonitrile
- Benzonitrile
- 3-Butenenitrile
- 2-Prophylene nitrile

Amines
- Indole
- 6-Methyl indole
- Pyrrole

Aldehydes
- Acrylaldehyde
- Benzaldehyde
- Formaldehyde
- Furfural
- 3-Methyl butenal
- 2-Methyl propanol

Miscellaneous
- Hexadecanoic acid
- 2-Methyl furan2,5-dimethyl furan
- 4-Methyl phenol
- Methyl pyrazine

through the skin and lungs. Acrylonitrile liberates hydrogen cyanide. Cyanide may exert its harmful effect by inhibiting intra-cellular oxygen utilisation through blocking cytochrome oxidase activity.

Potential mutagenicity of surgical smoke has been studied using *Salmonella typhimurium* with the standard *Salmonella* microsomal test (Ames test). Mutation of the bacteria was found after exposure to smoke created by electrocautery or laser ablation.[27,28] A dose-response relationship was also observed. Similarly, a dose-dependent reduction in clonogenicity of MCF-7 human breast cancer cells was observed when these cells were exposed to surgical smoke.[29]

Sugimura et al and Commoner et al first called attention to the mutagenicity of smoke from cooking food, especially meat.[30–32] More than ten kinds of mutagenic heterocyclic amines (HCAs) are produced by cooking or heating of meat or fish.[30] When HCAs were fed to experimental animals on a long-term basis, they developed cancers in many organs, including the colon, breast, and prostate.[30] The carcinogenic potential of these compounds is therefore well established. Whether long-term inhalation of smoke containing HCAs or surgical smoke will induce cancer development in humans is not yet certain. A recent study showed that lung cancer risk was not increased in operating room nurses.[33]

One of the major groups of chemical compounds produced by electrocautery is hydrocarbons (Table 2). It has been shown by Rivedal et al that 12 of the 13 hydrocarbons tested either induced morphological transformation or inhibited intercellular communication in Syrian hamster embryo cells.[34,35]

After subjecting the aerosols produced by laser irradiation of porcine tissues to several laboratory tests, Plappert et al concluded that the particulate fraction of aerosols have to be classified as cytotoxic, genotoxic, clastogenic, and mutagenic.[36]

Recommendations

To ensure safety of medical staff and patients, the best approach is to minimise the production of surgical smoke, increase the efficacy of the evacuation of smoke, and prevent inhalation of smoke by use of effective masks.

Minimise the production of surgical smoke

Unnecessary ablation of tissue should be avoided. Apart from production of surgical smoke, unnecessary ablation also increases the amount of dead tissue and risk of infection. Additionally, the production of smoke during laparoscopic surgery obscures the surgical vision field of surgeons and hence poses a potential risk to the patient.[3]

Increase the efficacy of smoke evacuation

A suction device should be considered, especially during laparoscopic surgery, to evacuate the smoke produced. A proper filter should also be used in the exhaust port of the collection device; otherwise the constituents of the smoke can escape into the operating room. Moreover, a valve or filter may be used in the laparoscopic port to avoid leakage of smoke.

The National Institute for Occupational Safety and Health (NIOSH) of the United States recommended the combination of general room and local exhaust ventilation to remove the airborne contaminants generated by surgical devices.[37] A suction device with a capture velocity of 100–150 feet per minute is recommended. A high efficiency particulate air (HEPA) or equivalent filter should be used at the same time. Staff should ensure proper maintenance of these devices and filters. The suction nozzle should be kept within 2 inches of the surgical site to ensure effective capture of airborne contaminants.

Prevention of inhalation by effective masks

Effective masks/respirators can protect health care workers from inhaling surgical smoke. Proper use of the mask is also important.

The most commonly used mask is a simple surgical face mask, which usually has three layers. Such masks are able to achieve 95–99% bacterial filtration efficiency (BFE) and 91–95% particulate filtration efficiency (PFE). BFE is a measure obtained by challenging a mask with bacteria contained in droplets that are 4 μm or larger. The most common method used nowadays is to generate aerosols by a nebulizer loaded with *Staphylococcus aureus* in 0.1% peptone solution. Microbiological culture and counting is then performed after 24 hours of inoculation. PFE is measured by challenging a mask with 0.1–0.3 μm aerosols. The main drawback of surgical masks (either ear-loop or tie) is that it cannot provide a snug fit so smoke or its constituents can still be inspired via the loose points. The other alternative is a respirator.

Health Care Particulate Respirators can be categorized into N, R and P classes.[38] In short, N stands for ***not*** resistant to oil, R for ***resistant*** to oil, and P for oil ***proof***. N class respirators are designed to filter out particles that are non-oil based. N95 can achieve > 95% filter efficiency when tested with ~0.3 μm sodium chloride aerosol. The R and P types of respirators are intended for filtering any particles with oil-based liquid aerosols. Grade 100 respirators can achieve > 99.97% filter efficiency when challenged with ~0.3 μm aerosols. Although NIOSH has not provided any guidelines on the use of respirators for surgical procedures, it seems that respirators that are at least N95 grade provide the best protection against surgical smoke produced during the use of electrocautery, lasers, or ultrasonic scalpels.

Current status

Various professional organisations, including the American National Standards Institute (ANSI), the Association of Operating Room Nurses (AORN), and the American Society for Laser Medicine and Surgery, have issued position statements recommending the use of local exhaust ventilation during procedures in which surgical smoke is produced.[39]

Nevertheless, a recent web-based survey of AORN members from various medical specialties and facilities throughout North America indicated that many facilities have not implemented best practices for protecting patients and health care workers from the hazards of surgical smoke.[39]

Conclusion

Surgeons and operating theatre staff should be made aware of the potential risks of surgical smoke. While some immediate untoward effects like odour and irritation of mucous membranes may appear minor, the potential long-term health hazards as discussed in this article should not be ignored. We should take appropriate measures to protect ourselves and our patients, as potential effects may only develop decades later.

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