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Surgical plume and its implications: A review of the risk and barriers to a safe work place

Abstract

Every year thousands of health care professionals worldwide are exposed to surgical smoke. There is evidence that this smoke consists of toxic gases, pathogens and particulate matter that is a hazard for patients and the perioperative team. Past research indicates that perioperative staff inconsistently comply with smoke evacuation recommendations. The aim of this study was to identify, review and discuss the issues related to surgical plume and its implications for patients and perioperative staff. The findings of this review relate to: surgical smoke content, its risks to the health of the perioperative staff, preventative measures, infection control measures, compliance with smoke evacuation systems, staff knowledge and barriers to implementing smoke evacuation practices. Of particular importance, the literature indicated that strong support from management and the implementation of regular staff education could improve practice for the management of surgical plume in the operating theatre.

Introduction

Surgical plume, also known as surgical smoke, cautery smoke, smoke-plume, diathermy plume, aerosol, bio-aerosol, vapour and air-contaminants^{1,2}, is a dangerous by-product produced by the electrosurgical instruments used to dissect tissue, provide haemostasis and perform laser ablation. These instruments include electrosurgery units, lasers, ultrasonic devices, high speed drills, burs and saws that produce heat and allow the surgeon to achieve the desired tissue effect^{3,4}. Surgical plume is created by the thermal damage of tissue which releases cellular fluid as steam and spews cell contents into the air. Chemical analysis lists its constituents to be 95 per cent water vapour and 5 per cent other chemicals and cellular fragments⁵. Surgical plume can pose health

risks to thousands of health care workers on an annual basis⁶. This article provides a review of the contemporary literature in relation to surgical plume, its composition, the risks it creates and management strategies.

Background

In this review, the authors aimed to identify, review and discuss the issues related to surgical plume and its implications for patients and perioperative staff. Health professionals in the perioperative environment are routinely exposed to surgical smoke, plume and aerosols produced by instruments used to dissect tissue and provide haemostasis. This can pose significant health risks, in particular for nurses and anaesthetists who spend more time in the operating room than ancillary workers, such as

orderlies, and surgeons because of clinic or ward schedules³. Strategies to educate perioperative staff about the risks and the use of smoke evacuation systems are essential for improved health outcomes.

Research has shown conclusively that surgical smoke is hazardous to personnel who are exposed to it daily^{2,3,7} and hence concerns have been raised regarding the infective, mutagenic and cytotoxic properties of surgical smoke from all the aforementioned devices⁷.

According to the Association for Perioperative Practice⁸ and Ulmer², surgical smoke is always present and it forms part of the patient-care environment whenever surgical or invasive procedures are performed. Surgical plume consists of 95 per cent water and 5 per cent other matter containing chemicals, dead and live cellular material (blood fragments, bacteria, viruses), toxic gases, vapors (e.g. benzene, hydrogen cyanide, formaldehyde) and lung-damaging dust^{2,3,5,9-11}. These components of the surgical plume are classified as 'physical', 'biological' and 'chemical'¹.

The physical component consists of particles that range in size from less than 0.01 microns to more than 200 microns¹. The largest particles (0.35 microns to 6.5 microns) are produced by ultrasonic devices, laser ablation produces particles of 0.3 microns and electrocautery produces particles of less than 0.1 micron. These ultrafine particles create a very fine dust¹ and anything less than 0.3 microns is able to bypass the lungs normal filtration mechanism and deposit in the alveolar region¹⁷. Particles that settle in the tiny air sacs transfer biological material and possibly cause infection, congestion and aggravation of conditions such as chronic obstructive pulmonary disease and asthma⁶. Repeated inhalation of

surgical smoke can induce acute and chronic inflammatory changes including congestion, pneumonia, bronchiolitis and emphysematous changes in the respiratory tract⁴.

The biological component of surgical plume contains blood and potentially infectious viruses and bacteria.

Examples of known contaminants include human immunodeficiency virus (HIV), human papillomavirus (HPV), bovine papillomavirus (BPV) and possibly hepatitis virus^{3,10,12-14}.

The chemical component of surgical plume contains more than 80 different toxic chemicals and by-products¹³, including:

- acrolein (a known carcinogen)
- acetonitrile
- acrylonitrile (long term exposure causes cancer)
- acetylene
- alkyl benzenes
- benzene (a known carcinogen)
- butadiene (a known carcinogen)
- butene
- carbon monoxide
- creosols
- ethane
- ethylene
- formaldehyde (a known carcinogen, used to preserve surgical specimens and as an embalming fluid)
- free radicals
- hydrogen cyanide (neurotoxin used in chemical warfare, is cardio-toxic)
- isobutene
- methane
- phenol
- polycyclic aromatic hydrocarbons
- propene

- propylene
- pyridine
- pyrrole
- styrene
- toluene (a known carcinogen)
- xylene^{3,12,13,15}.

Methodology

An integrative review is an examination of research that amasses comprehensive information on a topic, weighs pieces of evidence and integrates information to draw conclusions about the state of knowledge¹⁶. An integrative review in health care synthesises the results of several carefully designed studies on a specific question and provides a high level of evidence on the effectiveness of the health care intervention/s. Judgements may be made about the evidence to inform health care practice.

These reviews are detailed examinations of the available research; they are therefore only as effective as the research that they report on. Reviewers evaluate the evidence to determine an overall view of the practice/treatment in question. In this way, integrative reviews are able to summarise the existing clinical research on a topic^{17,18}.

A search was undertaken for studies and journal articles related to the risks of surgical smoke, chemical composition of surgical smoke, potential hazards of surgical smoke, implementing surgical smoke evacuation in the operating room and staff education. The author used Cochrane, PubMed and Google scholar databases to search for studies between 1990 and the present. Additional information was extracted from surgical textbooks, manufacturer's websites and government and non-government

agencies, such as the Australian College of Operating Room Nurses (ACORN), Association of periOperative Registered Nurses (AORN) and Association for Perioperative Practice (AfPP).

Findings

The findings of this study relate to the risks associated with surgical plume, the measures taken to prevent these risks and compliance with implementing preventative measures.

Risks

According to Ulmer², surgical smoke can be seen and smelled and these visible and odorous components of surgical smoke are the gaseous by-products of the disruption and vaporisation of tissue protein and fat. Surgical smoke has been described as being a nuisance at the very least and, at worst, carcinogenic^{2,10}. Additionally the carbon monoxide generated during electrocautery can cause headaches, burning and watery eyes, nausea and respiratory problems¹. These components irritating the lungs have a similar mutagenicity to cigarette smoke^{1,19}. Recent studies quantified the average daily exposure of surgical smoke in the operating room as equivalent to 27 to 30 cigarettes^{4,19} and the ablation of 1 gram of tissue as creating surgical plume with the mutagenic effect of smoking six unfiltered cigarettes^{12,19}. Benson et al.⁹ confirm that particles smaller than 5 microns are categorised as lung-damaging, and can result in acute and chronic respiratory changes which include emphysema, asthma and chronic bronchitis. Nascent Surgical²⁰ highlighted that poorly maintained theatre environments resulted in an increase in staff absenteeism and decreased productivity due to acute respiratory illness.

Studies with mice and rats have highlighted these significant health risks. Baggish and associates²¹ compared the effects of unfiltered laser smoke on rats' lungs. They all developed hypoxia and pulmonary congestion with bronchial hyperplasia and hypertrophy. A comparison control group were subjected to filtered plume, with no lesions identified³. Another study using mice showed that melanoma cells were released into the surgical plume after application of electrocautery to malignant tissue¹⁴, these cells were viable and cultured²² demonstrating that an organism can survive electrocautery²³.

In addition to airborne contamination, Ulmer² and Ball¹⁵ note that surgical smoke has a potential risk for patients during laparoscopic surgery and endoscopic procedures whereby the contaminants of the surgical smoke are absorbed into the patient's vascular system.

Concerns about the danger of surgical smoke are not new. In fact, 22 years ago concerns were raised that smoke absorbed through the peritoneal membrane resulted in an increase in methaemoglobin and carboxyhaemoglobin in the blood stream. This effect reduces the oxygen capacity of red blood cells, producing falsely elevated oxygen readings that could result in unrecognised patient hypoxia^{2,12}.

Electrocautery devices

According to Weld et al.²⁴, comparisons of bipolar, ultrasonic and monopolar devices found that monopolar devices produce the most surgical plume, impeding surgical visibility to the greatest extent.

Electrocautery devices and lasers heat target cells to the point of boiling, causing cells to rupture and disperse fine particles into the atmosphere. By comparison,

ultrasonic devices use a vibrating plate to cause cell rupture at a much lower temperature, causing cutting and coagulation simultaneously without an electrical current passing through the tissue⁷.

The literature has described that plume generated from laser surgery and electrocautery contains viable infectious particulate matter such as HPV, HIV and hepatitis B virus (HBV). Studies have reported that these infectious viruses can be transmitted to the upper respiratory tract through inhalation of surgical smoke. A case report published in 1991 revealed that a 44-year-old surgeon had developed laryngeal papillomatosis after using a laser to vaporise condyloma (Ball 2001). Another case report in 2013 reported the direct correlation between the developments of tonsillar cancer in two gynaecological surgeons and their exposure to surgical plume containing HPV 16 cells²⁵.

Preventive measures

Evacuation

Lewin et al.¹⁰, Ball³, Bigony²² and AfPP⁸ advocate the use of smoke evacuators and personal protection equipment (PPE). According to Ball³, there are a variety of smoke evacuators available depending on the amount of plume generated. An in-line smoke evacuator filter is appropriate for smaller amounts of plume while an individual smoke evacuator, which usually has a triple filtration system that includes a pre-filter, a charcoal filter and an ultra-low penetration air (ULPA) filter, is used if larger amounts of plume are generated^{3,15,26}. The pre-filter captures larger particles, the charcoal filter will remove toxic gases and odour while the ULPA filtration forces matter through a depth filter that is similar to a maze^{2,3,15,26}. Using high efficiency particulate air filters

(HEPA), ventilation exhausts and smoke evacuators is recommended to reduce exposure to the harmful effects of surgical plume and effectively purify the air in the operating room^{13,14,27-29}. Laparoscopic smoke can be evacuated through a special laparoscopic smoke evacuation device^{2,3,6,13-15,30}.

Infection control

According to the literature, the simple act of wearing a surgical face mask will generally filter particles to about 5 microns in size, while a high-filtration mask such a laser mask can filter particles to about 0.1 micron^{2,10,14,15,23,27,31-33}. Wearing gloves and a mask when disposing of smoke evacuator filters is also a vital control measure in reducing the transmission of infectious agents. Despite the benefits, Edwards and Reiman³⁴ state that the use of personal protection equipment (PPE) is low.

Compliance

Knowledge

Both Tregoning³⁵ and Khoshdel et al.³⁶ noted that there was a fundamental lack of understanding of the potential health risks from exposure to surgical plume, and recommended continuous professional development to improve staff knowledge about the risks to health and the use of local exhaust ventilation (LEV). The focal point of this exercise is to improve behaviours and practices in relation to the use of smoke evacuation tools and infection control procedures – a priority for perioperative nurses even in a general sense³⁷. Educating perioperative staff about the dangers of surgical smoke will support a culture whereby smoke evacuation is seen as a necessity and a key factor for workplace safety^{2,11,23,38-43}. Staff education should encompass the hazards of surgical smoke, infection prevention and methods

to minimise or eliminate surgical plume^{15,27}. A study by Ball⁴⁴ noted that compliance with smoke evacuation practices increased when nurses received training and education about the hazards of surgical smoke and methods of evacuating it. Chavis et al.⁴⁵ demonstrated that an improvement in staff knowledge correlated with increased use of surgical smoke management systems. Dawes⁴⁶ recommended that perioperative nurses become experts in the use of available tools to minimise exposure to surgical smoke. To assist with this education the smoke evacuator manufacturers⁴⁰ should be invited to provide regular in-service and onsite training.

Attitudes and barriers

According to Marsh⁴⁰ and Giordano⁴⁷, the cost of a smoke evacuation system, the significant price difference between a standard facemask and a high filtration one, misconception by staff that a standard facemask will provide sufficient protection against inhaling surgical smoke and a lack of knowledge about the dangerous risk of surgical smoke are all barriers to implementing efficient smoke evacuation procedures and taking preventive measures. Ball⁴⁴ stated that the greatest barriers to implementing smoke evacuation practices were the unavailability of smoke evacuation equipment, the refusal by surgeons to allow smoke evacuation devices to be used, the noise produced by the smoke evacuators and the complacency of perioperative staff. Bigony²² and Lewin et al.¹⁰ state that resistance to smoke evacuation can be attributed to expense, inconvenience, time constraints and a general lack of knowledge regarding the potential hazards associated with surgical plume exposure. Steege et al.⁴⁸ reported that the most frequent

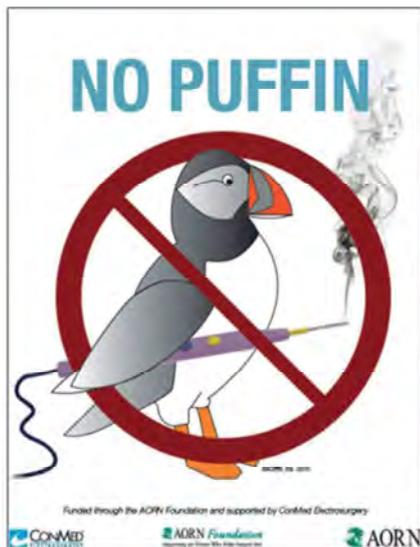
reasons for not using LEV and PPE during laser surgery and electrosurgery were 'not part of the protocol', 'not provided by the employer', 'exposure was minimal', 'not readily available in work area'. One 'other' reason for using a mask was when a patient had a known infectious disease, hence the most common 'other' reason for not using a respirator during electrosurgery was prior confirmation of the patient not carrying an infectious agent.

Role modelling and support

A cross-sectional survey conducted in the United States indicated that strong support from management was a key component to improved compliance⁴⁹. Chavis et al.⁴⁵ found that perioperative managers who were supportive of education programs and had allocated funds and time to support and encourage staff members to participate during their regularly scheduled work hours and over the year had also adopted and established best practice for the management of surgical plume in the operating room. This is further supported by Ball⁵⁰ who found that appropriate smoke evacuation practices improved when leaders supported the use of smoke evacuators.

Discussion

Improving compliance with best practice management of surgical plume in the operating theatre can be achieved through staff education and a supportive leadership team. Education should include evidence-based practices and strategies^{44,51-53} whereby nurses gain the essential skills to effect change within the perioperative environment. Support from management can also positively transform the working environment⁵⁴ enabling perioperative nurses to act as advocates, for both patients



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and the surgical team, to promote appropriate strategies including the use of smoke evacuation systems and PPE. The clinical nurse / team leader of the various surgical disciplines are the most suitably qualified personnel to educate their team members and promote best practice. Additionally, regular audits are recommended to ensure staff members are compliant with the use of smoke evacuation systems and PPE.

Regular in-service education sessions conducted by sales representatives can help staff members acquire or update knowledge about the hazards of surgical plume and the various devices to evacuate surgical plume.

Informative posters can be displayed in operating theatres, staff rooms and along theatre corridors to attract staff attention.

Policies that are simple and easy to follow should be developed to guide perioperative staff in creating an environment that reduces the exposure of patients and perioperative personnel to surgical plume⁵⁵⁻⁵⁷. Health care site policy should articulate that when surgical plume is generated smoke will be captured and filtered through the use of smoke evacuators or in-

line filters positioned on suction lines⁵⁵⁻⁵⁷. The policy should also state that smoke evacuation devices or equipment must be listed on all surgeon procedure cards for procedures that produce any surgical smoke⁴⁴. Smoke evacuation policies must be communicated to all perioperative staff⁴⁴. Compliance with smoke evacuation policies should be monitored as part of the quality improvement process^{2,44}.

Conclusion

The literature describes the hazards of surgical plume and concerns around the lack of compliance with prevention strategies. Since surgical plume is a controllable environmental occupational hazard, efforts to eliminate it can help to minimise health costs and improve the health of perioperative personnel and patients. Regular education sessions to assist staff to understand the danger of surgical plume and preventative measures can be an effective way to minimise exposure to surgical plume and improve compliance with using personal protection and smoke evacuation equipment.

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