REVIEW ARTICLE

Surgical smoke in dental practice: a potential biohazard

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ABSTRACT

BACKGROUND: With the advent of novel devices in surgery such as LASER and Electro surgery, surgical procedures in medicine and dentistry have become simpler. These devices offers the potential to reduce the intraoperative and postoperative bleeding, optimizes the healing and may reduce the healing time as well as the surgical complexity of the procedure. However, these devices are found to produce hazardous smoke during the procedure which is referred to as surgical smoke.

OBJECTIVES: The objective of this literature review is to identify the potential hazards of surgical smoke in dentistry and also to explain in brief about the methods of reducing smoke production in the operatory and thus reducing the health hazards it may cause.

METHODS: Articles pertaining to the key words "Surgical smoke", "surgical plume", "electrocautery smoke" and "laser smoke" were searched in MEDLINE database of references and abstracts on life sciences and biomedical topics. 37 articles (including reviews) were collected and analyzed for relevant information, segregated and the inferences were gathered into a structured literature review.

RESULTS: The available evidences on surgical smoke in the medical and dental literature showed that surgical smoke poses a definitive threat to the health of the operator and the staff in the operating room. The electrocautery smoke seemed to produce more harmful emissions compared to the laser plumes.

CONCLUSION: It can be concluded that dentists and the assisting staff should be educated about the potential risks of surgical smoke. The operating room should be equipped with proper evacuation system. Usage of respirators should be made mandatory so that both the patient as well as the operator should be at minimal risk from the emissions that are released during any procedures.

Key Words: *Surgical smoke; Health hazard; Technology*

INTRODUCTION

Surgical smoke, is not a novel issue in medical practice (1). dvancements in the technologies have led to the machineries that hazardous sources of air contaminants in the perioperative environment (1,2). Additionally, the awareness of this problem among the medical fraternity is less pronounced (3). Furthermore, there have been challenges in understanding the potential hazards associated with surgical smoke due to the gaps in the literature. Surgical smoke can be generated by

- Thermal, ultrasonic, and laser scalpels used in cellular ablation and various cosmetic surgeries (1)
- Electrocautery and diathermy units used in surgeries (2)
- High-speed electrical devices, often used in plastic and orthotic surgery (1,3)

HOW SURGICAL SMOKE IS PRODUCED?

Surgical smoke can be produced by any energy-generating device. The most common devices are electrocautery, electrosurgical units (ESU) and ultrasonic devices, LASER devices and powered instruments such as bone saws and drills. When the energy generating devices are used on tissues, it increases the inter and intra cellular temperature (100° Celsius (212° Fahrenheit) or higher) which produces surgical smoke at 100° Celsius.

The incidences of using such devices in dental practice is significantly high which puts majority of the dentists and the health care workers associated with the operating room at an increased risk of developing health hazards due to prolonged exposure to such emissions.

Harmful substances found in surgical smoke include

- Viable strains of bacteria such as *Staphylococcus aureus, Corynebacterium* and *Neisseria* (2)
- Infectious aerosols such as *Mycobacterium tuberculosis* (TB) (4)
- Transmittable cells of Human Papilloma Virus (HPV) Hepatitis B (HBV) (5)
- Toxic gaseous substances such as, benzene, hydrogen cyanide formaldehyde, methane and carbon monoxide (6)

OCCUPATIONAL SAFETY-STATEMENTS BY NATIONAL AND INTERNATIONAL AUTHORITIES

The National Institute for Occupational Safety and Health (NIOSH) published and distributed a Health Hazard Evaluation Report in 1985 which led to the official recognition of "Surgical smoke" as a potential health hazard (7). NIOSH, a department of the Centers for Disease Control and Prevention (CDC) stated that there is a "potential hazard from exposure to smoke generated by electrocautery" (7). Ever since this report had been published, efforts have been made to emphasize the risks of surgical smoke and also the sources of plumes which is now also referred to as aerosols, cautery smoke, diathermy plumes, plumes or smoke plumes (8).

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 recognized in surgical smoke, some of which are greatly hazardous and present in higher than negligible quantities. Chemicals that dominate in quantity in electrocautery smoke are hydrocarbons, nitriles, fatty acids, and phenols (9). Among them, Carbon Monoxide (CO) and acrylonitrile are of greater significance. There are other chemicals that are present in trace amounts which are also of significance which includes hydrogen cyanide, formaldehyde, and benzene. Carbon monoxide generation is of greater concern in laparoscopic procedures in general surgical procedures in which smoke is trapped and concentrated in the body cavities. According to the Occupational Safety and Health Administration (OSHA) the upper limit of ambient exposure to these substances is set at 2 ppm. Exposure levels of operating room staff have been demonstrated to be 1.0

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ppm-1.6 ppm, just under the established limit (10). Another potential toxic element is Hydrogen cyanide which is a toxic colorless gas that is easily absorbed by the human lungs, gastrointestinal tract, and the dermis. Once it combines with ferric iron in cytochrome oxidase, it inhibits cellular oxygen utilization leading to cell death. Additionally, it is found to act synergistically with CO in impairing tissue oxygenation. According to the United States Department of Health and Human short-term exposure to this substance is set at a limit of 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).

Although minimal, there is a significant amount of these toxic gases produced in the dental office. The common procedures performed in the dental practice with electrocautery includes minor surgical procedures such as soft tissue excisions, implant surgeries, periodontal surgeries such as full mouth LANAP (11), maxillofacial surgeries which lasts for a few hours. This poses a potential risk of developing respiratory disorders for the healthcare workers in the operatory. Electrocautery is found to be potentially less hazardous than laser smoke mode of transmission of disease. However, intact virions have been shown to be present in electrocautery smoke, and their infectivity has been demonstrated (12). In addition, the mutagenicity of electrocautery smoke has been estimated to be at least that of cigarette smoke (13), and has been further shown to vary in mutagenicity, depending on the type of tissue ablated (14). Benzene has also been studied to be highly responsible for the mutagenic character of the smoke produced by electrocautery.

LASER

The plume by laser tissue ablation generates numerous chemicals which includes benzene, formaldehyde, acrolein, CO, and hydrogen cyanide. Even at very low power densities, it has been noted that due to Carbon dioxide and Nd:YAG laser interaction the generated smoke plume contains the above said chemicals (15). With regard to the plume's infectious potential, even with lower irradiance levels more viable particles are produced. This observation was made as cellular clumps and erythrocytes have also been found (16). Intact strands of human papillomavirus DNA have been isolated from carbon dioxide laser plume during treatment of plantar wartsand in laser smoke from recurrent respiratory papillomatosis which supports the theory of potential infectivity (17-19). Viable bacteriophage has also been demonstrated to be present in laser plume (20,21). The mean aerodynamic diameter of particles carrying bacteriophage was found to be 7l m-55l m (22). Infectivity of the intact virions has been demonstrated (12). Other than Viruses, *in-vitro* experiments have also cultured bacteria from the plume (23,24). The presence of infectious viral genes, viruses and viable cells has been clearly demonstrated (25). Less infectivity has been found from the point of production and infection potential of smoke generated by laser tissue ablation is more than electrocautery (12,24).

Laser has been widely used in dentistry for procedures starting from cavity preparation, root canal therapy to extensive oral surgical procedures. Blake et al reported that precautions must be taken to protect against spreading infections when using lasers in the root canal therapy as they noted that cultures were positive for *E. coli* (26).

CELLS/CELLULAR SUBSTANCES

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 (27), other studies reported the presence of cell-sized fragments (28), morphologically intact but nonviable cells (29), and surgical smoke with viable cells (30,31). 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 demonstrated.

viable cells in laser and electrocautery smoke (32). 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.

HEALTH DISORDERS ASSOCIATED WITH EXPOSURE TO SURGICAL SMOKE (TABLE 1)

Occupational safety is of utmost importance in any work environment. The patient-care environments wherever surgical and invasive procedures are undertaken are bound to be exposed to surgical smoke (Figure 1). Since three decades, air quality of operating rooms is a cause of concern. Among the healthcare professionals, surgical smoke is a source of chronic irritation leading to health issues like respiratory illness, regular headaches, nausea, mucous membrane irritations and skin irritations. It can also be a cause for high rate of absence for work too.

Alp et al. (33) listed the potential risks associated with the exposure to surgical smoke for both patient and the health care professionals (Table 2). From the evidences, it is clear that surgical smoke poses a potential threat to the patient and the operating staff in the same environment alike. This fact is often ignored in both medical and dental settings.

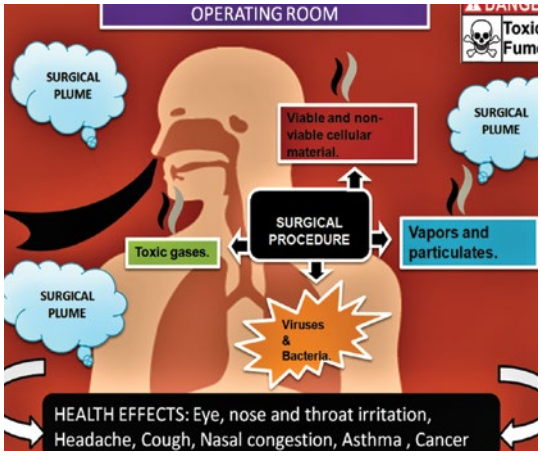

Figure 1) *Schematic representation of an operating room with surgical smoke and its health effects*

TABLE 1

Chemicals present in surgical smoke and their health effects (34)

Chemicals	Health hazard
Acetaldehyde Osha pel*: 200 parts per million (ppm) acgih tvl**: stel#: 25 ppm (a3 carcinogen) NIOSH REL##: Found to be carcinogenic	Eye, respiratory irritant and skin effects. Clinical exposure to vapors also include erythema, coughing, pulmonary edema, narcosis. Teratogenic. Irritation can be expected after an exposure of 50 ppm for 15 minutes. Facilitates intake of other contaminants in the atmosphere by bronchial epithelium.
Acrolein Osha pel: 0.1 ppm ($0.25\ mg/m^3$) niosh rel: $5\ mg/m^3$	Eye, skin, upper respiratory tract irritant. May increase blood clotting time and cause liver and kidney damage.
Acetonitrile Osha pel: 40 ppm Acgih tvl: 40 ppm	Nose irritant, throat asphyxiant. Has caused liver and kidney damage in animal models.
Benzene Osha pel: 1 ppm ($3\ mg/m^3$) Acgih tvl: 10 ppm ($32\ mg/m^3$) niosh rel: $0.1\ mg/m^3$	Headache, weakness, appetite loss, and fatigue. May cause bone marrow damage, injury to blood-forming tissue from chronic low-level exposure. The threshold value limit of parts per million inhaled intermittently over one year may alter nutritional status and gross metabolism.
Xylene Osha pel: 100 ppm; Stel: 150 ppm; Acgih tvl: 100 ppm	Well absorbed via respiratory tract. Respiratory tract irritation begins at 200 ppm. Chronic exposure associated with reversible changes in red and white blood cell counts and increases in platelet counts.
Formaldehyde Osha pel: 0.75 ppm ($2.5\ mg/m^3$) Acgih tvl: stel: 2 ppm (15 minutes) (a3 carcinogen)	Eye, nose, throat, and respiratory system irritant. Exposure causes cough and bronchospasm. Sensitizer. Studied to cause nasal tumors in rats.
Polyaromatic hydrocarbons (naphthalene) Osha pel: 10 ppm (naphthalene) Acgih tvl: 10 ppm (naphthalene); stel: 15 ppm	Absorbed via respiratory tract. Ocular, respiratory irritant. Wide range of sensitivity. Effects noted in very low doses. Exposure likely occurs via particle inhalation. Styrene and acrolein may increase inhalation effect.

Styrene Osha pel: 100 ppm (ceiling 200 ppm; peak 600 Ppm) (5 minutes) Acgih tvl: 213 ng/m^3=50 ppm	Respiratory irritant, short-term vapor exposure in animal studies found damage to the lining of the nose.
Toluene Osha pel: 200 ppm (ceiling 200 ppm; peak 600 ppm) Acgih tvl: 50 ppm Niosh rel: 100 ppm; stel: 150 ppm	Well absorbed via inhalation. Vapors irritate eyes, respiratory tract. Extensive documentation of effects in animal models, many related to central nervous system functions. High levels associated with teratogenesis

**Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL)*
***American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Value Limit (TVL)*
#Short-Term Exposure Limit (STEL)
##National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL)

MANAGING SURGICAL SMOKE IN THE OPERATING ROOM

With the advancement and evolving technology of tissue dissection and bleeding control, surgical smoke is relatively a newer occupational hazard. Surgical smoke, plumes and aerosols produced by instruments used to dissect tissue and provide haemostasis make the patients and healthcare professionals exposed to potential hazard. Minimizing the production of surgical smoke, increasing the efficacy of the evacuation of smoke, and preventing inhalation of smoke by use of effective masks are some methods to prevent exposure. As surgical smoke puts the health of both the patient as well as the operator at risk, a well-planned and designed evacuation system is necessary. Additionally, Smoke evacuators are in practice, they are devices that capture and filter the plume generated during electrosurgical procedures or laser procedures, thereby maintaining a safe environment for the surgical team and the patient (Figure 2). A smoke evacuation system should be appropriately selected depending on the need of the facility.

Minimize the production of surgical smoke

Tissue ablation should be avoided. Other than surgical smoke, the amount of dead tissue and risk of infection also increases with unnecessary tissue ablation. Over usage of the cautery or laser on a tissue results in excessive production of smoke. The surgical vision field of surgeons gets obscured and hence poses a potential risk to the patient (35).

Increase the efficacy of smoke evacuation

Proper evacuation and filter system must be used in order to avoid contamination of work environment. Regular portable suction devices may not help in evacuating the plumes completely and may also cause leakage of the gases back into the environment.

Adequate ventilation

The operating room should be equipped with positive pressure to facilitate easy escape of the gases produced within the operating room. The room should also allow entry of fresh air, in cases where the room is equipped with air conditioners, proper and repeated maintenance of the device especially the air filters are mandatory.

Prevention of inhalation

Higher quality filter masks or double masking may protect from the smoke produced. Routine surgical mask may not be as protective as masks with high quality filter. In addition, a smoke evacuation device or filter placed near (2 cm-5 cm) the electrocautery blade or on endoscope valves offers additional (and necessary) safety for operating personnel and patients.

The most commonly used mask is a simple surgical face mask, made of three layers. Such masks will achieve 95%-99% bacterial filtration efficiency (BFE) and 91%-95% particulate filtration efficiency (PFE) (8). The disadvantage of surgical masks (either ear-loop or tie) is that it fails in providing a snug fit therefore smoke or its constituents are inspired via those loose points. A suggested alternative is a respirator (8). There are three types of respirators N, R and P classes. N stands for nonresistant to oil, R for resistant to oil, and P for oil proof. N class respirators are designed in order to filter particles that arenon-oil based. N95 masks can achieve >95% filter efficiency when tested with ~0.3 µm sodium chloride aerosol. The Rand P types of respirators are designed for filtering any particles with oil-based liquid aerosols. Grade 100 respirators can achieve >99.97% filter efficiency when exposed to ~0.3 µm\aerosols (8).

Figure 2) *Smoke evacuators that are commercially available (a) Smoke Shark 2 Evacuation Unit incl. Smoke Filter (Elite Medical ™); (b) Plume Safe® Turbo*

TABLE 2

Risks of exposure to surgical smoke (33)

Risks of exposure to surgical smoke
• Acute and chronic inflammatory respiratory changes(eg, emphysema, asthma, chronic bronchitis)
• Anemia
• Anxiety
• Carcinoma
• Leukemia
• Cardiovascular dysfunction
• Colic Dermatitis
• Eye irritation
• Headache
• Hepatitis
• HIV
• Hypoxia or dizziness
• Lacrimation
• Lightheadedness
• Nasopharyngeal lesions
• Nausea or vomiting
• Sneezing
• Throat irritation
• Weakness

CONCLUSION

Dentists and assisting staff should be educated about the potential risks of surgical smoke. In comparison between Laser plume and electrosurgery smoke, the electrosurgical smoke seemed to be potentially more hazardous than laser smoke. The operating room should be equipped with proper evacuation system. Usage of respirators should be made mandatory so that both the patient as well as the operator should be at minimal risk from the emissions that are released during any procedures. Effective methods to control this environmental occupational hazard, ultimately will be very beneficial to staff and patients in an operatory.

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