SURGICAL SMOKE

WHAT WE KNOW TODAY

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INTRODUCTION

For more than fifteen years, operating room personnel have expressed concern for the potential adverse health effects of laser and electrosurgical smoke. Knowing that cigarette and barbecue smoke contain chemical carcinogens, healthcare workers reasonably concluded that surgical smoke might be even more hazardous because it potentially contained not only carcinogenic chemicals, but also viruses and bacteria.

Frequently expressed complaints have included respiratory imitation, itching eyes, particularly in contact lens wearers and the noxious odor produced by plume, to name a few. Additionally, some surgeons have allegedly acquired human papilloma virus (HPV) lesions as a result of their exposure to laser plume in treating venereal warts. Collectively, healthcare workers have reason to be concerned. There are 30,000 operating rooms in the United States, constituting the workplace for two to eight persons each. Annually 24 million operations are performed. 85% using electrosurgery and 5% using lasers; these individuals spend much of their working day in an environment where electrosurgical and laser smoke are often present.

Patients are also exposed to these same carborne hazards, but with the advent of laproscopic surgery, concern for the patient has become even more of an issue. When electrosurgery or lasers are used in the peritoneum into the patient's bloodstream, resulting in potentially deleterious effects.

This review examines the scientific literature bearing on the potential hazards of surgical smoke, the current regulations and recommendations of overseeing agencies, adverse health effects from exposure to carcinogenic components, and an examination of available protection measures. This analysis is intended to provide a basis for individual healthcare workers to make informed decisions regarding protective actions to be taken when surgical smoke is likely to be generated.

SCIENTIFIC LITERATURE

Air quality issues and occupational concerns in the operating suite have led to several attempts to define the potential contaminants in surgical smoke. Early research concentrated on plume generated from laser tissue vaporization, since practitioners using this modality recognized the noxious nature of the heavy vaporous-by-products and complained that the laser plume impaired visualization of the target tissue. Although laser plume has been studied more intensively than electrosurgical smoke, laser plume and electrosurgical smoke are similar in composition[3] and effect [4]. Lasers and electrosurgery affect tissue by rapidly heating cells, causing cell rupture and vaporization. Electrosurgical smoke may be of even greater concern than that generated from laser because of the lower levels, and hence lower temperatures, characterizing electrosurgery[5]. Furthermore, electrosurgery is used 15 to 20 times more frequently than surgical lasing, and is more likely to involve extensive flap dissections, transaction of large bulky muscles, or coagulation of large bleeding surfaces, all situations that typically generate copious amounts of smoke.

Despite strong interest in understanding the dangers associated with surgical smoke, designing research to define these hazards has been challenging. Studies have included human subjects, but lack state-of-the-art analytical techniques or an adequate number of subjects. Alternately, they may have utilized accepted analytical techniques but were performed on non-human tissue. These factors have sometimes limited possible conclusions. For example, insensitive analytical techniques may not have quantified all potentially dangerous chemicals that were present. Or, non-human tissue models may not have accurately depicted what might have been found using human subjects. Still, the research to date illustrates important facts in four primary areas discussed below:

- Chemical Composition of Laser and Electrosurgical Smoke
- Viral Elements in Surgical Smoke
- Exposure to Blood Aerosols and Transmission Potential of Plume constituents
- Patient Exposure During Laproscopic Procedures

Chemical Composition of Laser and Electrosurgical Smoke

Kokosa and Eugene[6] investigated the presence of chemicals in plume generated by CO_2 and Nd:Yag in lasing beef liver. These investigators found that even at very low power densities, several potentially dangerous chemicals were formed. Using a variety of sampling techniques and gas chromatography (GC) with mass spectroscopy (MS), they demonstrated the presence of several known carcinogens, irritants or toxins, listed in Table 1.

Table 1: Chemicals Present in Plume from CO_2 Lasing of Beef Liver	
Acrolein	Polyaromatic Hydrocarbons (PAH's)
Acetaldehyde	Styrene
Benzene	Toluene
Formaldehyde	O, M, P-Xylenes

Although no levels surpassed established Permissible Exposure Limits (PELs) and Threshold Limit Values (TLVs) the mere presence of the listed chemicals should cause concern. It has been suggested by an EPA researcher that human subject selection for exposure studies may impact one's ability to generalize findings to a wide variety of populations. This is based on the finding that study subjects are generally volunteers, often from university campuses. These groups are homogeneous, to control for internal validity, usually comprised of very healthy, never smoking, white males.[31] It is clear that workers in operating suites differ from the study groups from which standards are derived. Operating room workers are predominately female, representing a wide range of ages and racial backgrounds, and may be immunosupressed, due to their chronic exposure to ill patients. Consequently it seems that permissible concentrations for these workers should perhaps be lower because adverse health effects may occur at lower concentrations in these individuals.

In a subsequent study exploring a cholesterol model and laser beam interaction at various power settings, Kokosa et al[7] confirmed their earlier findings. Additionally, they refined their previous conclusions to indicate that production of polyaromatic hydrocarbons (PAHs) could be reduced by using lower power settings.

The only patient-based study to evaluate the components of electrosurgical smoke was completed by the National Institute of Occupational Safety and Health (NIOSH) in l989.[8] In response to a request from Bryn Mawr Hospital, Bryn Mawr, Pennsylvanis, NIOSH studied breathing zones during two reduction mammaplaties, finding benzene soluble fractions in excess of the Occupational Safety and Health (OSHA) PEL and trace amounts of hydrocarbons, but no PAHs. The absence of PAHs is at variance with the Kokosa laser findings. At least three explanations are possible: PAHs may not be formed using lower energy electrocoagulation; Kokosa's beef liver and cholesterol models may not adequately reflect human tissue; or PAHs may have been present, but

were not detectable in the Bryn Mawr study, where a less sensitive High Performance Liquid Chromatography (HPLC) assay was used for analysis. NIOSH also made solvent extracts of airborne particles collected from the rooms and found some were mutagenic, using the standard Ames test[9]. These results confirm earlier mutagenicity research using CO^2 laser on canine tongue in the early 1980's.[10] Although the NIOSH study involved only two subjects, it supports the concept that smoke from individual patients may differ in amount and mutagenic content. Universal precautions would seem warranted, since it is unlikely that operating room workers can determine preoperatively which patients' smoke will have a greater potential adverse health effect.

Viral Elements in Surgical Smoke

The presence of airborne infectious particles in laser and electrosurgical smoke has become of paramount concern in this era of increased awareness of infectious diseases such as HPV, hepatitis, and acquired immunodeficiency syndrome (AIDS). Vaporization of tissue at high temperatures has been assumed to produce sterile smoke, but several investigators have recovered viral DNA from surgical smoke.[11 14]Research with infectious agents under realistic conditions in humans is lacking, no doubt because such testing would be complicated by the risk of infection. Because of the dangers associated with infection, limiting exposure during surgery seems prudent.

Garden et al reported on viral DNA content in papillomavirus-infected verrucae (warts). These investigators demonstrated the presence of intact viral DNA in the plume of CO_2 laser smoke from both bovine and human papillomavirus (HPV) warts. Their study indicated that viral DNA particles become airborne as warts are lased.

Ferenczy and colleagues[12] sampled 110 patients, smoke evacuator filter canisters, collection tubing, and the nasopharynx, eyelids, and ears of the surgeon for HPV DNA before and after surgery. Sixty-five of the patients had warts that were positive for HPV. Following surgery using a smoke evacuator, these investigators cultured HPV DNA in one of five smoke evacuator filter canisters. The nasopharynx, eyelids and ears of the surgeon were negative for HPV before and after surgery. These researchers concluded that HPV contamination of the operator was unlikely when a smoke evacuator was used.

Sawchuk et al[13] also studied papillomavirus in wart vapor, from both laser and electrocautery treatment. This group found HPV DNA in five of eith laser-derived samples, and four of seven electrocautery-derived samples. Detection of HPV DNA was observed in all but one positive sample, regardless of whether electrosurgery or laser was used thus treatment modality did not appear to impact on the presence of HPV DNA. To test infectivity potential bovine papillomavirus (BPV) can be tested for cell transformation since no infectivity assay is available for HPV infectious BPV particles will cause focal cell transformation, but naked DNA will not. Sawchuk and his colleagues found that bovine warts treated with either electrocoagulation or laser were capable of cell transformation, although laser vapor induced more foc than did electrocoagulation.

Baggish and associates[14] studied the interaction of CO: laser on concentrated tissue culture pellets infected with human with immunodeficiency virus (HIV) p24 HIV gag antigen, an antigen to a viral core protein on the HIV molecule, was cultured after one week in 3 of 12 segments of collection tubing used in the experiment Polymerase chain reaction (PCR) analysis was performed on particulate debris to determine whether proviral DNA was present. This was found to be "strongly positive" in four cases sampled immediately, and in three cultured cases on day 3 and day 7. One additional sample was "positive" on day 10 and 14. These results would seem meaningful since the presence of proviral DNA indicates a potential for transmission both immediately and several days after the plume was generated.

Surgeons have reported alleged HPV transmission by inhalation even though this probably occurs at a very low rate. HIV DNA studies are less convincing, since no known transmission has been reported via airborne virus. However, it is known that a mechanism of HIV infection is the CD4 receptor site, found on alveator macrophages in virto by bonding with the CD4 receptor sites.

Exposure to Blood Aerosols and Transmission Potential of Smoke Constituents

The previously described studies indicate the presence of a variety of chemicals and viral contaminants in electrosurgical and laser plume. The NIOSH study[15] stands out amongst the others because it showed that contaminants were present in the actual breathing zones of operating room workers.

Other investigators have attempted to link contaminant presence with exposure and transmission potential. Using breathing zone sampling to quantify exposure to blood aerosols. Heinshohn and colleagues [16 17] determined the particle size distribution of aerosols for a variety of powered surgical tools, including electrocautery. Electrocautery in both the cut and coagulation modes aerosolizes blood into particles in the respirable size range.

In a later study, these investigators studied potential exposure in the breathing zones of surgeons and first assistants.[17] Workers wore cascade impactors to represent effective cut-off aerodynamic diameters (ECADs) of 14.8um, 3.5um, and 0.52um. ECADs describe the collection characteristics of impaction sampling devices. At a stated ECAD, 50% of the particles collected are larger than the ECAD and 50% are smaller.

The significance of the selected ECADs is indicated in Table 2. Hemoglobin (HB) content was used to indicate the presence of blood aerosol at given levels within the impactor. Data were collected in orthopedic, vascular, and obstetric surgical procedures. Utilizing power tools known to produce aerosols in the particle size ranges described in the authors' previous study, hemoglobin was detected in the various stages of the impactor as described in Table 2.

Table 2: Impactor ECAD Configurations, Significance and Samples Detected

Impactor Stage	ECAD Configuration	Significance of Configuration	Hb Detected Samples	Percent Detected
Stage 2	14.8 um	Nasopharyngeal region	26	90%
Stage 5	3.5 um	Tracheobronchial & gas-exchange region	19	66%
Stage 8	0.52 um	CD4 receptor sites found on alveolar macrophages	11	38%

These findings show that the surgeon, first assistant, and perhaps other operating room personnel are exposed to inhalable blood aerosols, many of which are too small to be captured by a surgical mask. More importantly, these aerosols may enter the breathing zone because surgical masks do not seal to the face.

To investigators have attempted to define airborne transmission of viruses using a retrospective epidemilological approach [18 19]. Conclusions might be challenged in these types of studies, since control for all known risk factors was not possible, the control group of surgeons was likely to have been exposed to blood aerosols at some time before the study, and septic status of patients was not always fully known.[17]

Lobraico and associates[18] conducted a retrospective study on the likelihood of transmission of HPV from CO_2 lased warts. They also gathered data on surgeon demographics, and protection measures taken such as the use of surgical gloves, masks, sterile technique, and suction. A questionnaire was mailed to 4500 healthcare workers, mostly surgeons and nurses (18.7%), 794 responding specifically regarding HPV. Respondents included a variety of specialty groups, including gynecologists (413), podiatrists (123), dermatologists (112), surgeons (56) and nurses (58) constituting the largest groups to return the survey. The overall incidence of acquired lesions was 26/794 (3.2%). The incidence of acquired lesions and their locations are shown in Table 3.

Table 3: Sites of Acquired Lesions

Specialty	Forearm	Hands	Face	Neck	Shoulders	% of Positive Response
Dermatology	0	15	2	0	0	65.4
Gynecology	1	1	2	1	1	26.9
Podiatry	0	1	1	0	0	7.6
Total	1	17	5	0	1	100.0

Labraico and colleagues concluded that since no lesions were reported in the buccal mucosa or larynx among all physicians reporting, that the risk of developing lesions via an airborne route was insignificant among the group of healthcare workers responding. Since response was related to exposure status, response bias must be regarded as a factor in the observed association between exposure and disease. Despite the small number of observations, the authors also indicated that locations of acquired lesions were more randomly distributed among gynecologists and podiatrists.

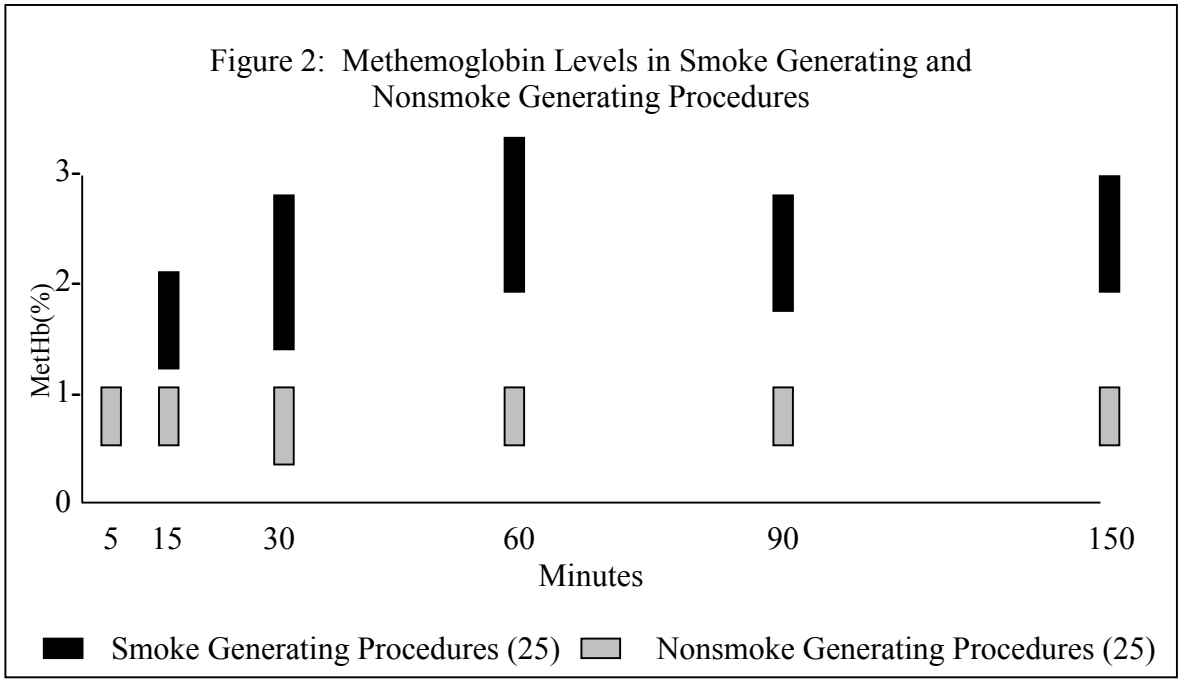
In another epidemiological study, Gloster et al[19] compared CO_2 laser surgeons to two large population-based patient control groups. Although there was no statistical difference in the total number of warts acquired by either group (surgeons, 5.4% incidence and patients, 4.7% incidence), the difference in location of warts within the two sub-populations was striking as shown in Table 4.

Table 4: Comparison of HPV Lesions in CO_2 Laser Surgeon and Patients					
Anatomic site of Warts	No. of Surgeons with warts	Incidence (%)	No. of Patients with warts	Incidence (%)	P Value
Plantar Surface	1	3	1613	26	0.004
Nasopharynx	4	13	37	0.6	0.001
Genital/perianal area	0	0	1274	21	0.004
Face	8	26	-	-	-
Hands	18	58	-	-	-
Miscellaneous	-	-	3200	-	-
Total	31		6124		

The authors concluded that CO_2 laser surgeons are at increased risk of acquiring nasopharyngeal warts through inhalation of laser plume. Interestingly, three of the four physicians with nasopharyngeal warts had used CO_2 lasers to treat genital lesions. The Gloster results seem to contradict the Lobraico conclusion that proper sterile technique reduces HPV transmission, since all four laser surgeons with nasopharyngeal warts wore gloves and masks, and used smoke evacuators. Gloster et al concluded that it was likely that the nasopharyngeal lesions were transmitted by plume since gloves were worn and masks are known not to seal to the face. They also emphasized the importance of locating the distal end of the smoke evacuator within 2 cm of the irradiated site to minimize plume escape.

Patient Exposure During Laproscopic Procedures

Two investigators have studied health risks that patients may experience from exposure to surgical plume.[12] Ott[1] investigated methemoglobin levels in patients undergoing endoscopic surgery using either laser or electrocautery and a control group in which no energy sources were used. Methemoglobin is an oxidative product of hemoglobin, and in unable to carry oxygen to tissues. Additionally, methemoglobin increases the oxygen affinity of hemoglobin, inhibiting normal hemoglobin's ability to off load oxygen to the tissues. Figure 2 shows a comparison of methemoglobin levels in patients treated with smoke producing modalities and control subjects. All patients had normal methemoglobin levels before anesthesia was introduced, but a significant elevation was observed in patients where smoke was produced.



Beebe et al[2] studied nine patients undergoing laparoscopic cholecystectomy to determine whether carbon monoxide is produced by electrocautery of tissue. These investigators found that carbon monoxide was present in the peritoneal cavity at mean concentrations of 345 ppm (range 25-1600 ppm), within 5 minutes following the use of lectrocautery. At the end of the operation, the mean concentration was 475 ppm (range 100-1900). Both the 5 minute and terminal levels were well above the 35 ppm level set by the Environmental Protection Agency (EPA) for a 1-hour exposure.

The existing studies provide a sound foundation for further research into the dangers associated with both electrosurgical and laser plume. Chemical studies should include more breathing zone sampling, "state-of-the-art" analytical techniques, and a meaningful number of human subjects. Studies of viral transmission should include appropriate scientific controls as discussed above to give the data validity and to allow individuals affected by smoke exposure to make informed decisions about the health hazard relevant to their individual roles.

These studies and others[4 20]justify concern, both for operating room workers and their patients, regarding chemical and viral components present in laser and electrosurgical plume. Although much of the existing literature focuses on laser plume, several investigators have been able to demonstrate similarities between electrosurgical and laser smoke. Taken together, these studies provide a reasonable basis for regulatory recommendations and precautions to reduce exposure to potentially harmful surgical smoke, and to cold aerosols as well.

Regulations and Recommendations of Overseeing Agencies

A number or agencies have recommended precautions to be taken to minimize potential ill health effects of surgical smoke. Even researchers, who may not be convinced of the danger [13,15,18,21,22]have taken a proactive precautionary stance.

OSHA

The Occupational Safety and Health Administration (OSHA) is the federal agency charged with enforcing regulations that provide employees with a healthy and safe work environment. OSHA has not yet drafted specific standards regarding surgical smoke. However, they have developed PELs for many compounds known to be carcinogenic and/or potentially hazardous. Standard PELs have been established for the following compounds that have also been quantified in surgical smoke:

Total particulate matter	Aldehydes
Benzene	Nitrosamines
Benzene soluble particles	Other mutagenic compounds
Toluene	Pathogens
Polycyclic aromatic hydrocarbons	

The "General Duty Clause" provides OSHA with a statute to regulate workplace conditions for which there is no set standard. This clause requires that:

> "...each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees."[23]

Considering the extensive literature and industry focus that has accumulated on laser and electrosurgical plume, surgical smoke should constitute a recognized hazard in the context of the "General Duty Clause". Additionally, at a recent round table discussion sponsored by the AORN foundation, an OSHA official described the General Duty Clause as a mechanism to address occupational concerns regarding surgical plume[29].

NIOSH

The National Institute for Occupational Safety and Health (NIOSH) serves under the Center for Disease Control within the U>S> Department of Health and Human Services. NIOSH is charged with investigating potential occupational health risks and recommending action to OSHA. NIOSH itself has no regulatory or enforcement authority, but has recommended that "engineering ventilation controls be used to

minimize the acute health effects and reduce the potential for long range chronic disorders."”

ANSI

The American National Standards Institute (ANSI) is the central body responsible for the identification of a single set of voluntary standards. ANSI standard developers include professional societies, trade associations, and other organizations (e.g., labor, consumer and industrial). ANSI promulgated requirements to use smoke evacuators during laser procedures. These regulations refer to electrosurgery, but fall short of requiring the use of smoke evacuators in these procedures, stating:

*Electrocautery knives are often used both separately and simultaneously with HCLS. These devices have been found to produce the same type of airborne contaminants as produced by laser-tissue interaction. ...Local exhaust ventilation is used to capture airborne contaminants as near as practical to the point of evolution without altering surgical effectiveness to produce an effective removal rate...”

AORN

The Association of Operating Room Nurses (AORN) has been a strong advocate for a safe and healthful work environment for operating room nurses and staff. Although this organization has no regulatory authority, it has made persuasive recommendations for the management of potentially harmful surgical smoke.[10] The 1995 AORN Recommended Practice states:

“Patients and perioperative personnel should be protected from inhaling smoke generated during electrosurgery.” The recommendation goes on to state that...”an evacuation system should be used to remove surgical smoke, and...placement of the evacuator suction...should be as close to the source of the smoke as possible to...maximize smoke capture and enhance visibility at the surgical site”.[29]

ACGIH

The American Conference of Governmental Industrial Hygienists(ACGIH) is a voluntary organization concerned with industrial air quality and exposure to potentially harmful contaminants. This organization has set TLVs (Threshhold Limit Values) for exposure to a number of known carcinogens and other potentially harmful compounds. TLVs differ from PELs in that PELs are maximum exposure limits, whereas TLVs represent time-weighted average concentrations under which most people can work continuously for eight hours per day. TLVs are often lower than OSHA standards, and are ferequently based on more recent data. Although TLV recommendations are not requirements, they are recognized among those concerned with environmental air quality including OSHA.

Table 5 indicates OSHA PELs and ACGIH TLVs and their possible associated health effects for a number of chemicals that have been quantified in surgical smoke. It would be noted that some individuals may experience adverse health conditions at levels lower than those established by these limits because of individual susceptibility, pre-existing medical conditions, or hypersensitivity. In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or the personal habits of the worker to produce health effects even if occupational exposures are within the established levels. Therefore, it may be inadequate to consider only singular chemical exposure levels in determining the potential for negative health effects.

Sample levels from prevailing studies are compared to PEL and TLV exposure limits established by OSHA and ACGIH for industrial environments, not indoor air such as that found in an operating room. As mentioned previously, exposure levels may be set using study subjects that may not accurately represent personnel typically working in operating suites in the United States.[31] These factors may also influence the actual limits of exposure.

Table 5: Chemical, Exposure Limits, and Associated Health Effects

Constituent	OSHA PEL	ACGIH TLV	NIOSH REL	Associated Health Effects	Levels Found in Surgical Smoke	Additional Notes
Acetaldehyde	200ppm	STEL: 25ppm A3 carcinogen	Carcino-genic without further classif-ication	Eye, skin, and respiratory tract irritant. Clinical exposure to vapors also included also include erythemea, coughing, pulmonary edema, narcosis. May be teratogenic. Irritation can be expected after 50 ppm for 15 minutes. May facilitate uptake of other atmospheric contaminents by bronchial epithelium.	Laser – Present but not quantified [6]	IARC – 2B, Possible human carcinogen. EPA-2B, Possible human carcinogen.
Acrolein	0.1ppm A3 carcinogen		5 mg/ cu. m.	Eye, skin, upper respiratory tract irritant. May inrease blood clotting time, liver and kidney damage.	Laser – 4.3mg/50mg tissue. [4]	
Acetonitrile	40ppm	40ppm		Nose irritant throat asphyxiant. Has caused liver and kidney damage in animal models.		
Benzene	1ppm, 3 mg/cu.m.	10 ppm, 32mg/ cu. m.	0.1 mg/cu m	Headache, weakness, appetite loss, fatigue. May cause bone marrow damage, injury to blood forming tissue from chronic low-level exposure. MAN TDLoPPM inhaled intermittently over one year period may alter nutritional status and gross metabolism.	ES-Benzene soluble fraction .7 to 6.7 mg/cu m[6] Laser – 12.8mg/50mg tissue[6]	Carcino-genic by ACGIH, IARC, and OSHA
Formaldehyde	.75ppm (2.5 mg/cu m)	15 min. STEL: 2 ppm A3 carcinogen		Eye nose, throat, and respiratory system irratant. Exposure may cause cough and bronchospasm. Sensitizer. Shown to cause nasal tumors in rats.		
Polyaromatic Hydrocarbon s (PAHs)	Napthalene: 10ppm	Napthalene: 10ppm		Absorbed via the respiratory. Ocular, respiratory irritant. Wide range of sensitivity. Effects noted in very low doses. Exposure likely occurs via particle inhalation Styrene, acrolein may increase inhalation effect.		
Styrene	100ppm Ceiling: 200ppm Peak: 500ppm (5 min)	213 ng/cu m 50ppm		Respiratory irritant. Short term vapor exposure in animal studies found damage to lining of nose.	ES – Probable presence in benzene-soluble fractoion.[8] Laser –present but not quantified.[6,7]	IARC – Possibly carcin-ogenic to humans
Tolulene	200ppm Ceiling: 200ppm Peak: 600ppm	50ppm	100ppm STEL: 150ppm	Well absorbed via inhalation. Vapors irritate eyes, respiratory tract. Extensive documentation of effects in animal models, many related to CNS function. High levels associated with teratogenesis.	ES – Probable presence in benzene-soluble fractoion.[8] Laser –present but not quantified.[6,7]	
Xylene	100ppm STEL: 150ppm	100ppm		Well absorbed via respiratory tract. Respiratory tract begins at 200ppm. Chronic exposure associated with reversible changes in red and white blood cell counts and increases platelet counts.	ES – Probable presence in benzene-soluble fractoion.[8] Laser –present but not quantified.[6,7]	

Protection Methods and Their Effectiveness

A variety of protection measures are available to reduce exposure to potentially harmful components of surgical plume. However, operating suite personnel may not be fully informed regarding the effectiveness of various protection mechanisms.

Surgical Masks

Many healthcare workers assume that surgical masks provide adequate protection from airborne contaminants and pathogens. However, these masks are primarily designed to protect patients from airborne droplets from operating room personnel. Coughing, sneezing and talking generate large aerosol particles; surgical masks are designed to trap these rather than the significantly smaller surgical aerosols that could carry pathogens. To address both circumstances, masks would have to be designed to collect a wide range of particle sizes; from less than 0.1 um for surgical aerosols to several micrometers, to collect aerosol particles generated from sneezing or similar activities.

In a study performed by Chen et al[25] filtration performance of surgical masks was investigated. The protection provided by surgical masks depends on both the filtration efficiency and the degree of perimeter leakage through open spaces between the mask'' edge and the wearer'' face. These investigators tested two masks; one a molded-cone design and the other a flat mask with a layer of filter material. The capture of sub-micrometer particles was more efficient in the flat mask than in the molded-cone mask. However, 0.3 um particles penetrated the flat mask 25% of the time at an airflow of 5 L/min. As expected, the flat mask efficiently captured 95% of the aerosols larger than 3 um at all flow settings. Even so, neither of the two tested masks could be considered sufficient at removing submicrometer sized particles. Furthermore, in the flat mask, perimeter leakage further increased the possibility of aerosols penetrating the breathing zone.

Another study by Tuomi[26] verifies these conclusions. This investigator tested face seal leakage as a function of particle size for four surgical masks. Particles between the sizes of 0.3 to 10 um were tested. This study also showed that filtration material is reasonably efficient for larger particles but great variation exists for smaller particles. These studies helps to explain the Sawchuk et al[13] results. Sawchuk and associates concluded that surgical masks were a sufficient mechanism to limit exposure. However, their study design did not account for possible exposure due to perimeter leakage.

Dedicated Smoke Evacuators

Dedicated smoke evacuation systems are another mechanism to limit exposure to surgical plume. These systems are quite effective at removing odor and particulate matter that might otherwise be inspired by operating room workers, and have been used almost universally in surgeries involving the laser. Generally, smoke evacuators transport

surgical plume away from the operative field via a capture device, a vacuum, and a filtration system. Commonly, smoke evacuators employ a three stage filtration process that includes a prefilter for capture of gross particulate, high efficiency filtration systems for capture of submicron particulate, and charcoal for gas absorption and odor removal.

Filtration mechanisms are rated by the Institute of Environmental Sciences (IES) based on their ability to capture specific size particles at specific efficiencies. Ultra Low Penetrating Air (ULPA) filters are employed in many smoke evacuators. These filters are capable of trapping 0.12 um particulate with an efficiency of 99.9999%. Put another way, ULPA filters capture submicron particles with such efficiency that only 1 in 1,000,000 particles will not be captured by the filter. Filters that are ULPA quality or better should be used to achieve adequate particulate capture efficiency.

The performance of the vacuum system is dependent upon the power setting chosen, the distance between the capture device and the source of the plume, and the diameter and length of the capture device and accompanying tubing. Manufacturers offer a variety of tubing set-ups for use as capture devices. Historically, these have been perceived as bulky, requiring the scrub nurse to hold them near the source of the plume. This is impractical since the nurse is busy with other activities and the location where electrosurgery is being used varies.

This problem and the increased focus on the evacuation of electrosurgical plume has resulted in the development of capture devices that attach directly to the electrosurgical pencil, providing a more "hands-free" approach than was previously available.

As indicated previously, most overseeing agencies recommend the use of a dedicated smoke evacuation system to remove surgical plume from the operative site. Several make recommendations to place the capture device as near the origin of surgical smoke as possible. In addition, much of the scientific literature notes the use and appropriate location of the capture device. [3 11 12 13 14 18 19.] All of these sources recommend the placement of the capture device as close to the source of smoke as possible. Clearly, dedicated smoke evacuation systems with sufficient filtration capability and "hands-free" capture devices will diminish the potential for exposure to surgical plume and its potentially dangerous components.

Summary

A multitude of information is available to warrant protection from the potential dangers of surgical smoke. Scientific research indicates that the associated potential risks are significant. Chemical carcinogens, toxins and irritants have been quantified in plume, both in patient-based studies and in tissue models. These constituents are known to be associated with respiratory irritation, itching eyes, and noxious odors. In addition, viruses including HPV and HIV have been cultured from surgical plume. Although transmission potential of HPV has been alleged, it has been difficult to prove. Even so, limiting exposure during surgery seems prudent.

Patients must be protected as well since the literature confirms their exposure to significant levels of surgical smoke, carbon monoxide and methermoglobin in laparoscopic procedures. Although the short-term exposure limits and dangers may not be clear, caution is in order. Governmental agencies such as OSHA and NIOSH have established guidelines for exposure limits within varying time frames. Voluntary organizations such as ANSI and AORN have recommended the use of smoke evacuation systems, and the industrial hygiene organization, ACGIH, has also developed exposure guidelines. This abundance of information should not be ignored. To this end, the surgical team is best positioned to take action. Since the potential for infection, irritation, and undesirable physiological changes from exposure to surgical smoke exists, the surgical staff should increase knowledge of hazards and the available protection methods. In addition, they should educate fellow team members about these issues, and secure dedicated smoke evacuation for assigned cases in their operating suites. Finally, universal precautions should be utilized when discarding system disposables or decontaminating reusable components.

Glossary of Terms

Area Sample: An air sample collected in the vicinity of a process.

Breathing Zone: An imaginary globe of a two foot radius surrounding the head.

Ceiling Value: The level at which exposure to a given substance cannot be exceeded within a given workday, at any time.

High Performance Liquid Chromatography (HPLC): An analytical method to determine the contents of an unknown sample where the sample is in the liquid phase. It is less sensitive than GC/MS.

Gas Chromatography/Mass Spectroscopy (GC/MS): Gas Chromatography is an analytical method that vaporizes the sample, and diffuses it through a liquid or solid absorbent for differential absorption. Mass Spectroscopy involves the observation and study of spectra of absorbed or emitted light.

Permissible Exposure Limit (PEL): An exposure limit that is published and enforced by OSHA as a legal standard.

Personal Sample: An air sample collected in the breathing zone of workers to assess their exposure to airborne contaminants.

Short Term Exposure Limit (STEL): An exposure limit allowed over a short duration, usually 15 minutes.

Threshold Limit Value (TLV): A time-weighted average concentration under which most people can work consistently for 8 hours per day, day after day, with no harmful effects. TLVs and accompanying precautions are published annually be the American Conference of Governmental Hygienists.

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