



Medical



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Clinical Update

## Surgical Smoke

### Introduction

Operating room personnel have been exposed to surgical smoke and aerosol for years without fully understanding whether they contain hazardous particles. Not until the introduction and acceptance of laser surgery technology in the early 1980s did the constituents of surgical smoke come under scrutiny. The research to date has focused on four potential health risks to operating room personnel and patients: hazardous chemicals, viable viruses, viable cells, and nonviable particles.

The mechanism of surgical smoke – or plume – generation by electrosurgery units (ESU) and laser systems is the same. While being used to cut, coagulate, vaporize, or ablate tissue, the devices heat the target cells to the point of boiling causing the membranes to rupture. This allows odor causing chemicals and cellular contents including virus, steam, and fine particles to be dispersed into the air or pneumoperitoneum. As a result, the qualities of the surgical smoke generated by these two methods are very similar. With ultrasonically activated devices no burning occurs, but an aerosol is created.<sup>83</sup>

- Chemicals in surgical smoke are irritants, mutagenic, cytotoxic, and carcinogenic.<sup>6,8</sup>
- Patients absorb chemicals through the peritoneum.<sup>6, 16, 17, 31</sup>

- Viable cells and virus are present in surgical smoke.<sup>35-40, 45, 47</sup>
- Harmonic Scalpel creates a bioaerosol containing blood and tissue particles of respirable size.<sup>83</sup>
- Particles in surgical smoke cause pathologic changes and damage to the lungs of rats.<sup>61, 62</sup>
- Hazards of surgical smoke have been recognized by AORN, OSHA, NIOSH, and ANSI.<sup>4, 70, 75, 77</sup>
- Standard surgical masks are not an effective barrier.<sup>42, 72, 74</sup>

While research has not made a direct link between surgical smoke, aerosol, and identifiable cases of infectious disease, it is commonly accepted that smoke and aerosol does present a hazard.

This document is a review of the scientific literature, recommendations, and regulations related to surgical smoke for the purpose of helping healthcare workers make an educated decision when considering products offering protection from exposure to surgical smoke.

### Potential Health Risks Associated with Surgical Smoke

#### Hazardous Chemicals

The noxious odor of surgical smoke is a negative aspect of working in a modern operating room. In addition to being annoying and unpleasant, this odor is an indication of the contents of the smoke. The smell is a conglomeration of chemical by-products from the burning of proteins and lipids when using laser or electrosurgical instruments.<sup>1,2</sup> In addition to possible long term effects, these chemicals cause headaches, as well as irritation and soreness in the eyes, nose, and throat.<sup>1-4</sup>

#### Chemical Analysis

Smoke generated through the use of lasers and electrocautery in surgical procedures has been subject to a variety of differing analytical procedures. One important method utilizes the technologies of gas chromatography and mass spectroscopy to determine the nature and quantity of the exact chemicals in surgical smoke. Numerous researchers have analyzed chemical constituents of surgical smoke. From these analyses, the following list of chemicals in both laser and electrocautery surgical smoke has been compiled in Table 1. <sup>5-11</sup>

## Potential Health Risks Associated with Surgical Smoke (continued)

**Table 1**

Chemicals in Surgical Smoke

▶ Acrolein	▶ Butene	▶ Ethyl benzene	▶ Methane	▶ Propene
▶ Acetonitrile	▶ 3-Butene nitrile	▶ Ethylene	▶ 6-Methyl indole	▶ Propylene
▶ Acrylonitrile	▶ Carbon disulfide	▶ Ethynyl benzene	▶ 2-Methyl propanol	▶ 2-Propylene nitrile
▶ Acetylene	▶ Carbon monoxide	▶ Formaldehyde	▶ 3-Methyl butenal	▶ Pyridine
▶ Alkyl benzenes	▶ Creosols	▶ Furfural	▶ 2-Methyl furan	▶ Pyrrole
▶ Benzaldehyde	▶ 1-Decene	▶ Hexadecanoic acid	▶ 4-Methyl phenol	▶ Styrene
▶ Benzene	▶ 2,3-Dihydro indene	▶ Hydrogen cyanide	▶ Methyl pyrazine	▶ Toluene
▶ Benzo nitrile	▶ Ethane	▶ Indole	▶ Phenol	▶ 1-Undecene
▶ Butadiene	▶ Ethene	▶ Isobutene	▶ Polyaromatic Hydrocarbons	▶ Xylene

### Regulated Exposure Levels and Health Effects

Many of the specific chemicals listed above are known to be dangerous. OSHA has set limits for allowable worker exposure.<sup>12</sup> Exposure limits, health effects, and measured levels of various chemicals in surgical smoke are summarized in Table 2. The health effects associated with these chemicals

represent exposure in excess of the permissible exposure limits (PELs) published by OSHA. The purpose of PELs is to prevent these health effects from occurring and to provide a safe work environment for persons potentially exposed to these chemicals.

**Table 2**

OSHA Chemical Exposure Limits and Associated Health Effects<sup>12</sup>

Chemical	OSHA Permissible Exposure Limit		Associated Health Effects	Levels in Surgical Smoke
	Parts per Million (ppm)	mg/m <sup>3</sup>		
Acetaldehyde <sup>5</sup>	200 TWA* 150 STEL**	360	Eye, skin, and respiratory-tract irritant. Clinical exposure to vapors also include erythema, coughing, pulmonary edema, and narcosis. May be teratogenic. May facilitate uptake of other atmospheric contaminants by bronchial epithelium. International Agency for Research on Cancer (IARC) listed as possible carcinogen.	DNM***
Acetonitrile <sup>6</sup>	40 TWA 60 STEL	70	In animal studies, has been found to be embryotoxic and teratogenic in rodents exposed to levels sufficiently high to cause maternal toxicity.	DNM
Acrolein <sup>5</sup>	0.1 TWA 0.3 STEL	14	Irritation of nose, eyes, and the upper respiratory tract, but lung edema can occur after exposure to high tissue concentrations.	4.3 µg/50 mg
Acrylonitrile <sup>6</sup>	2 TWA 10 STEL		Short-term exposure can cause eye irritation, nausea, vomiting, headache, sneezing, weakness, and lightheadedness. Long-term has been shown to cause cancer in laboratory animals and has been associated with higher incidences of cancer in humans. Repeated or prolonged exposure of the skin to acrylonitrile may produce irritation and dermatitis.	DNM
Benzene <sup>5,9,14,15</sup>	1 TWA 5 STEL		Irritation in eyes, nose, and respiratory tract, headache, dizziness, and nausea. Long-term exposure even at relatively low concentrations. May result in various blood disorders, ranging from anemia to leukemia. Many blood disorders associated with benzene exposure may occur without symptoms. <sup>13</sup>	Benzene Soluble 0.7-6.7 mg/m <sup>3</sup> 0.2-7.4 mg/m <sup>3</sup> 71 µg/m <sup>3</sup> 12.8 µg/50 mg tissue
Carbon monoxide <sup>16-20</sup>	35 TWA 200 STEL		Carbon monoxide readily combines with hemoglobin to form carboxyhemoglobin (HbCO) and methemoglobin (metHb). Excessive accumulations of HbCO and metHb cause hypoxic stress in healthy individuals as a result of reduced oxygen-carrying capacity of the blood. In patients with cardiovascular disease, such stress can further impair cardiovascular function.	326 +/- 360 ppm 425 ppm (115-2100) 209 +/- 19 ppm 814 +/- 200 ppm 475 ppm (100-1900)
Ethyl benzene <sup>9</sup>	100 TWA 125 STEL	435	Irritation of nose, eye, and the upper respiratory tract.	31 µg/m <sup>3</sup>

## Potential Health Risks Associated with Surgical Smoke (continued)

**Table 2**

OSHA Chemical Exposure Limits and Associated Health Effects<sup>12</sup> (continued)

Chemical	OSHA Permissible Exposure Limit		Associated Health Effects	Levels in Surgical Smoke
	Parts per Million (ppm)	mg/m <sup>3</sup>		
Formaldehyde <sup>5,10</sup>	0.75 TWA 2 STEL		Formaldehyde is highly irritating to upper respiratory tract and eyes. Concentrations of 0.5 to 2.0 ppm may irritate the eyes, nose, and throat of some individuals. Formaldehyde is a potential cause of cancer in humans. Exposure has been associated with cancers of the lung, nasopharynx and oropharynx, and nasal passages. Rats exposed to formaldehyde at 2 ppm developed benign nasal tumors and changes of cell structure in the nose as well as inflamed mucous membranes of the nose. Structural changes in epithelial cells in the human nose have also been observed. <sup>21</sup>	3.4 µg/50 mg tissue 0.2-0.8 ppm
Hydrogen Cyanide <sup>10</sup>	10 TWA 4.7 STEL	11	Long-term exposure showed increase in symptoms of headache, weakness, throat irritation, vomiting, dyspnea, lacrimation, colic, and nervousness.	100 ppm
Polyaromatic Hydrocarbon; Naphthalene <sup>5</sup>	10 TWA 15 STEL	50	Vapor causes headache, loss of appetite, and nausea. Exposure causes optical neuritis, corneal damage, and kidney injury.	3.6 µg/50 mg tissue
Styrene <sup>5,9</sup>	50 TWA 100 STEL	2	Respiratory irritant causing wheezing, shortness of breath, and chest tightness. A narcotic, and a neuropathic agent causing sleepiness, fatigue, headache, difficulty in concentration, malaise, nasal irritation, and nausea. ACGIH and EPA list as possible carcinogens.	21 µg/m <sup>3</sup> DNM
Toluene <sup>5,9</sup>	100 TWA 150 STEL	2	Headache, fatigue, lack of appetite, lassitude, temporary amnesia, impaired coordination, and anorexia. Also a suspected liver toxin.	460 µg/m <sup>3</sup> DNM
Xylene <sup>5</sup>	100 TWA 150 STEL	435	Headache, fatigue, lassitude, irritability, and gastrointestinal disturbances as most common symptoms.	DNM

\* TWA: Time-weighted average over 8 hour period

\*\* STEL: Short-term exposure limits for 15 min. period

\*\*\* DNM: Detected but not measured

While these studies have measured the individual chemical concentrations and compared them to regulated exposure levels, no work has been done to measure the effect of their combined presence in the smoke on individuals working in the operating room.

### Biologic Analysis

An additional method for analyzing surgical smoke is to evaluate the mutagenic effect of the smoke condensate on living cells. Even with the long list of chemicals that have been identified in surgical smoke, it is suspected there are many more constituents not identified to this point.<sup>2,14,24</sup> For this reason, some researchers have chosen a biologic approach in the analysis of surgical smoke. One study measured the effect of the electrosurgical smoke condensate on MCF-7 human breast carcinoma cell colony formation and found it caused a significant reduction. They concluded the smoke is cytotoxic.<sup>23</sup>

A number of studies have also evaluated the mutagenic effect of smoke on living cells using the Ames test. It entails the exposure of two strains of *Salmonella typhimurium* bacteria to smoke condensate, followed by observation of the amount of mutation that occurs in the cells. Three different evaluations of surgical smoke generated by either laser and electrocautery have confirmed its mutagenicity.<sup>10,24,25</sup> Tomita *et al.* suggest the mutagenic potency of electrocautery smoke to be twice that of laser smoke. **The authors compared the amount of**

**mutagenic condensate from cautery of one gram of tissue is equivalent to three cigarettes for laser and six cigarettes for electrocautery smoke.**<sup>25</sup>

### Hazards to Patients from Chemical Exposure

Absorptive properties of the peritoneum are well documented. Encompassing more than 2 m<sup>2</sup>, the peritoneal lining can absorb osmotic fluids at rates exceeding 30 mL/hr through transcapillary channels as well as specialized pores measuring 4 to 12 µm.<sup>26-29</sup> Absorption is further increased by the vasodilatory effect of CO<sub>2</sub> on the surface vasculature of the peritoneum and an increase in intra-abdominal pressure to 15 mm Hg (the usual pressure of laparoscopic pneumoperitoneum).<sup>8,30</sup>

The primary concern investigated in the research, related to the patient's exposure to surgical smoke, has been the absorption of carbon monoxide (CO) into the patient's blood. The formation of CO is caused by a chemical reaction between hydrogen ions (produced during combustion) and carbon dioxide (CO<sub>2</sub>, used to create the pneumoperitoneum).<sup>16</sup> Carbon monoxide readily combines with hemoglobin to form carboxyhemoglobin (HbCO) and methemoglobin (metHb). Excessive accumulations of HbCO and metHb cause hypoxic stress in healthy individuals as a result of the reduced oxygen-carrying capacity of the blood. In patients with cardiovascular disease, such stress can further impair cardiovascular function.<sup>12</sup>

## Potential Health Risks Associated with Surgical Smoke (continued)

In a series of publications, one researcher has measured metHb increases from less than 1 to 4.2% and for HbCO from less than 2 to 18% in a study of 25 patients receiving either laser or electrocautery laparoscopic hysterectomy or laparoscopic vaporization of endometriosis; intraperitoneal CO increased to a mean of 425 ppm within two minutes (range 115 to 2100 ppm).<sup>17</sup> Ninety-six percent of patients in smoke-producing procedures experienced statistically increased metHb levels after 15 minutes of surgery; all patients demonstrated a statistically significant increase at 30 minutes and longer. A third of the patients returned to baseline levels three hours after surgery; one patient required six hours to return to baseline. The experimental group experienced more postoperative headaches, double vision, muscle weakness, and nausea vomiting. All patients had the same anesthetic and were matched for age and sex.<sup>6,17,31</sup> Other studies measured CO concentrations ranging from 100 to 2100 ppm, with averages all in excess of OSHA standards for environmental exposure.<sup>12,16,18-20</sup>

One study took specific steps to prevent the effects of CO on their patients. They demonstrated that with hyperventilation of 50 to 100% oxygen and the continuous and aggressive evacuation of intra-abdominal smoke there was no increase in HbCO and metHb levels and thus no risk of CO poisoning.<sup>32</sup>

### Viable Viruses

As more medical professionals become aware of the dangers of exposure to human immunodeficiency virus (HIV) and Hepatitis B virus (HBV), a number of studies have been conducted to examine virus viability in electrocautery and laser smoke. There are numerous examples of viable virus being identified in CO<sub>2</sub>, ER:Yag, ND:Yag laser and electrocautery smokes generated at a range of power settings.<sup>35-40</sup> One study demonstrated HIV DNA contained in laser smoke generated by a CO<sub>2</sub> laser remained viable for 14 days.<sup>35</sup> They further speculated:

Although we did not examine electrocautery by-products for the presence of HIV, one could surmise that the smoke would likely contain HIV DNA. An alarming fact is the smoke evacuators are not commonly employed in conjunction with electrocautery and electrosurgical operations.<sup>35</sup>

A survey study, in 1994, demonstrated a significantly higher incidence of nasopharyngeal lesions among CO<sub>2</sub> laser surgeons in comparison to the control group. The presence of this difference in conjunction with the fact that inhalation of laser plume is a likely means by which Human Papillomavirus (HPV) can be transmitted to the upper airway indicates CO<sub>2</sub> laser surgeons are at increased risk of acquiring nasopharyngeal warts through inhalation of the laser plume.<sup>41</sup> Finally, a case study was published linking the laryngeal papillomatosis in an ND:Yag laser surgeon to virus particles in laser plume from one of his patients.<sup>42</sup>

While the studies have not been unanimous in their findings, the majority do support legitimate concern for viable viruses in surgical smoke. In addition, the aerosol created by ultrasonically

activated (harmonic) devices contains particles of tissue, blood and blood bi-products of a respirable size.<sup>83</sup>

### Viable Cells

The primary concern behind this work seems to be a combination of the risk of infection to operating room staff and concern for dissemination of cancer cells within the pneumoperitoneum leading to port-site metastasis. Due to variation in energy levels, surgical device, dwell time, and testing techniques, the studies to date have been inconclusive.

Numerous researchers, however, have demonstrated that intact cells and blood components are aerosolized by lasers, ESUs, and ultrasonic scalpels.<sup>39,44-49</sup> Two of these published studies have concluded the cells remain viable.<sup>45,47</sup>

One research team, in particular, tested cell viability using both the trypan blue and MTT assays to determine cell viability in electrocautery smoke. They found viable cells using MTT and not trypan blue. They also found lower energy and shorter bursts were more likely to produce viable cells in the plume.<sup>47</sup>

In addition to the work described above (which has investigated the existence of intact cells in surgical smoke) the liberation of cells in the process of performing laparoscopic surgery has been considered a plausible vector for port-site metastasis by many other investigators.<sup>39,50-56,82</sup> These studies measured tumor growth at the port sites. It is speculated, liberation of cells may also be caused by the manipulation of tissues with instruments during laparoscopic procedures. These cells are then transported via gas flow in the pneumoperitoneum due to leakage at the ports in what has been called a “chimney” effect.<sup>57,58,82</sup> The investigators have documented metastases at port sites remote to the removal of the cancerous tissue.<sup>39,50-56,82</sup>

### Nonviable Particles

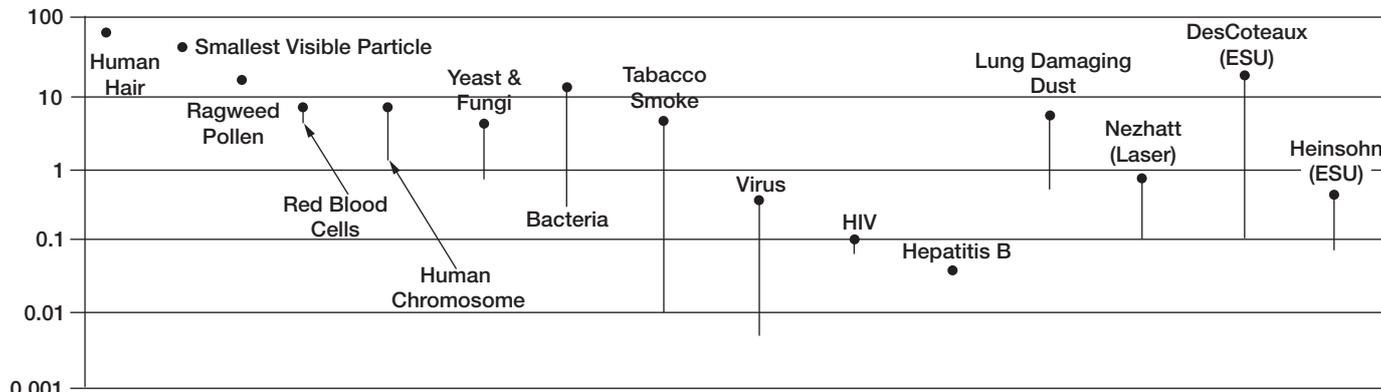
Regardless of chemical or biologic make-up of surgical smoke contents, the nature of small particles can also present a hazard to patients and personnel. Particles in the size range of 0.5 to 5.0 µm are considered “lung damaging dust” because they can penetrate to the deepest regions of the lung.<sup>59,60</sup>

Nezhat *et al.* measured particle-size ranging from 0.1 to 0.8 µm when using a CO<sub>2</sub> laser.<sup>43</sup> Later, DesCôteaux measured the size range to be 0.1 to 25 µm when using electrocautery.<sup>45</sup> Heinsohn *et al.* measured particles ranging from 0.07 to 0.42 µm in electrocautery smoke.<sup>46</sup> Figure 1 compares these results to other particle sizes.

Two research teams have conducted studies to determine the effect of surgical smoke particulate on the lungs. Baggish *et al.* demonstrated after long-term exposure, fine particulate matter resulting from the use of a CO<sub>2</sub> laser was deposited in the alveoli of test animals.<sup>61</sup> The presence of these particles caused congestive interstitial pneumonia, bronchiolitis, and emphysema.<sup>61</sup> These findings were confirmed by Wenig *et al.* They documented pathologic changes in the lungs of rats from both Nd:YAG laser and electrocautery smoke.<sup>62</sup> These findings are not unlike what is expected from long-term inhalation of other types of particulate matter.<sup>63-69</sup>

Figure 1

Relative Size of Small Particles



### Regulations and Recommendations

Current guidelines and recommendations pertaining to surgical smoke based on research to date are summarized below:

#### Occupational Safety and Health Administration (OSHA)

An estimated 500,000 workers are exposed to laser or electro-surgical smoke each year, including surgeons, nurses, anesthesiologists, and surgical technologists. Surgical plumes have contents similar to other smoke plumes, including carbon monoxide, polyaromatic hydrocarbons, and a variety of trace toxic gases. As such, they can produce upper respiratory irritation, and have in-vitro mutagenic potential. Although there has been no documented transmission of infectious viral fragments, particularly following treatment of venereal warts, may exist. Local smoke evacuation systems have been recommended by consensus organizations, and may improve the quality of the operating field.<sup>70</sup>

Although OSHA does not specifically require the use of smoke evacuation systems, it does regulate staff exposure to a wide range of substances commonly found in surgical smoke plume. OSHA has established PELs for many of these substances. Additionally, OSHA's general duty clause requires each employer to:

Furnish to each of his/her 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.<sup>71</sup>

The primary objective is to control occupational diseases caused by breathing air contaminated with harmful substances. This is to be accomplished through accepted engineering controls if feasible, or through the use of appropriate respirators. \*Note: Surgical masks used to prevent contamination of the patient are not certified for respiratory protection of medical employees.<sup>72</sup>

Because blood borne pathogens have been identified in surgical smoke, the following OSHA regulation also applies:

When there is occupational exposure, the employer shall provide, at no cost to the employee, appropriate personal protective equipment such as, but not limited to, gloves, gowns, laboratory coats, face shields or masks and eye protection, and mouthpieces, resuscitation bags, pocket masks, or other ventilation devices. Personal protective equipment will be considered "appropriate" only if it does not permit blood or other potentially infectious materials to pass through to or reach the employee's work clothes, street clothes, undergarments, skin, eyes, mouth, or other mucous membranes under normal conditions of use and for the duration of time which the protective equipment will be used.<sup>73</sup>

In a document, yet to be released, entitled "Information for Health Care Workers Exposed to Laser and Electro-surgery Smoke," OSHA is expected to place laser and electrocautery smoke on a more equal level of hazard. This document will also discuss personnel, workplaces, types of ESUs and lasers, physical hazards of lasers and ESUs, constituents of smoke, pathophysiological effects of smoke, infectious potential of laser and ESU plume, methods of protection, engineering controls, personal protective equipment, conclusions, and recommendations.<sup>74</sup>

#### American National Standards Institute (ANSI)

Electrosurgical devices and instrumentation often are used both separately and simultaneously with health care laser systems. These devices have been found to produce the same type of airborne contaminants as produced by laser-tissue interaction, and these contaminants should be evacuated from the surgical site.<sup>75</sup>

In operations that use Class 4 lasers, the vaporization of target tissue produces laser generated airborne contaminants (LGAC)... Analysis of the LGAC has shown the presence of gaseous toxic compounds, bioaerosols, dead and live cellular matter, and viruses.<sup>75</sup>

## Regulations and Recommendations (continued)

### Association of peri-Operative Registered Nurses (AORN)

Exposure to smoke plume generated during electrosurgery should be reduced.<sup>11</sup>

Exposure to smoke plume generated during laser surgery should be reduced by implementing a variety of engineering controls.<sup>11</sup>

The release of gas, electrosurgical smoke, and laser plume during endoscopic surgery exposes the surgical team to blood products, fluid, and cellular debris. A system for evacuation provides protection from eye, nose, and lung irritations and reduces the risk of exposure to infectious agents. Patients and peri-operative personnel should be protected from inhaling the smoke generated during electrosurgery.<sup>11, 76</sup>

### National Institute of Occupational Safety and Health (NIOSH)

During surgical procedures using a laser or electrosurgical unit, the thermal destruction of tissue creates a smoke byproduct. Research studies have confirmed that this smoke plume can contain toxic gases and vapors such as benzene, hydrogen cyanide, and formaldehyde, bioaerosols, dead and live cellular material (including blood fragments), and viruses. At high concentrations the smoke causes ocular and upper respiratory tract irritation in health care personnel, and creates visual problems for the surgeon. The smoke has unpleasant odors and has been shown to have mutagenic potential. General room ventilation is not sufficient by itself to capture contaminants generated at the source (i.e., the surgical site).<sup>77</sup>

## Protection Offered by Masks

Surgical masks do not provide adequate protection to workers when exposed to laser or ESU smoke.<sup>42,72,74</sup> Standard surgical masks are used to prevent cross-contamination from the healthcare provider to the patient. As demonstrated in various studies, specifically designed masks,

called respirators, are still not absolute barriers and leakage in the seal of the mask to the face is also a source of penetration. No studies have measured the effectiveness of these respirators in removal of chemicals and odor. Table 3 summarizes the results of various mask evaluations in the literature.

**Table 3**

Summary of Mask Penetration Studies

Mask Type	Flow Rate	Challenge Particle Size	Organism	Penetration
Cone Surgical Mask <sup>78</sup>	30 L/min	0.3 µm	NA	80%
Flat Surgical Mask with Filtration Layer <sup>78</sup>	30 L/min	0.3 µm	NA	50%
Nuisance Dust Respirator <sup>78</sup>	30 L/min	0.3 µm	NA	80%
Dust-Mist Respirator <sup>78</sup>	30 L/min	0.3 µm	NA	9%
Dust-Mist-Fume Respirator <sup>78</sup>	30 L/min	0.3 µm	NA	2%
Sub-micron Surgical <sup>79</sup>	28 L/min	0.5 x 2 µm	<i>M. chelonae</i>	3%
Dust-Mist Respirator <sup>79</sup>	28 L/min	0.5 x 2 µm	<i>M. chelonae</i>	3%
Dust-Mist-Fume Respirator <sup>79</sup>	28 L/min	0.5 x 2 µm	<i>M. chelonae</i>	0.04%
High Efficiency Particulate Arrestor (HEPA) <sup>79</sup>	28 L/min	0.5 x 2 µm	<i>M. chelonae</i>	0.01%
Surgical Mask <sup>80</sup>	12.5 L/min	0.9 to 1.8 µm	<i>M. luteus</i>	11%
Surgical Mask <sup>80</sup>	12.5 L/min	0.9 to 1.8 µm	<i>M. luteus</i>	73%
Surgical Mask with Filtration Layer <sup>80</sup>	12.5 L/min	0.9 to 1.8 µm	<i>M. luteus</i>	5%
Surgical Mask with Filtration Layer <sup>80</sup>	12.5 L/min	0.9 to 1.8 µm	<i>M. luteus</i>	3%
Full Face Respirator <sup>80</sup>	30 L/min	0.9 to 1.8 µm	<i>M. luteus</i>	1%
Full Face Respirator with 4mm Seal Leak <sup>80</sup>	30 L/min	0.9 to 1.8 µm	<i>M. luteus</i>	5%
Surgical Mask with Filtration Layer <sup>81</sup>		0.9 to 1.8 µm	<i>M. luteus</i>	5%

Surgical Mask with Filtration Layer and Leakage<sup>81</sup>

0.9 to 1.8 µm *M. luteus* 25%

#### Nuisance Dust (ND) Respirator

Dust is defined as a solid particle formed by crushing or other mechanical breakage of a parent material.

#### Dust-Mist (DM) Respirator

Mist is a liquid particulate aerosol, typically formed by physical shearing of liquids such as nebulizing, spraying, or bubbling.

#### Dust-Mist-Fume (DMF) Respirator

Fume is a solid particulate aerosol produced by the condensation of vapors or gaseous combustion products.

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## Conclusion

The variety of laser and electrosurgical instruments used in today's operating rooms share one thing in common; they all generate smoke. We have discussed the four elements of surgical smoke which present potential health risks to patients and operating room staff; hazardous chemicals, viable virus,

viable cells, and nonviable particles. The body of literature reviewed in this document validates the concerns regarding surgical smoke. It is meant to be a resource, for those people exposed to surgical smoke, to understand the risk and choose the best method or product to address their needs.

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## References

1. Ball K. Surgical smoke: is it safe to breathe? *Today's Surg Nurse*. 1996; 18(5):16-21.
2. Ulmer B. Surgical Smoke: Clearing the Air. *Minim Invasive Surg Nurs*. 1996; 10(1): 2-4.
3. Lobraico RV, Schifano MJ, Brader KR. A retrospective study on the hazards of the carbon dioxide laser plume. *Journal of Laser Applications*. 1988 Fall; 6-8.
4. Hoglan M. Potential hazards from electrocautery plume. *Canadian Operating Room Nurs J*. 1995; 13(4):10-16.
5. Kokosa J, Eugene J. Chemical composition of laser - tissue interaction smoke plume. *Journal of Laser Applications*. 1989 July; 59-63.
6. Ott DE. Smoke production and smoke reduction in endoscopic surgery: preliminary report. *Endosc Surg Allied Tech*. 1993; 1:230-3.
7. Internal Pall Corporation Study
8. Hensman C, Baty D, Willis RG, Cuschieri A. Chemical composition of smoke produced by high-frequency electrosurgery in a closed gaseous environment. An in vitro study. *Surg Endosc*. 1998; 12(8):1017-9.
9. Sagar PM, Meagher A, Sobczak S, Wolff BG. Chemical composition and potential hazards of electrocautery smoke. *Br J Surg*. 1996; 83(12): 1792.
10. Moss CE, Bryant C, Stewart J, Whong WZ, Fleeger A, Gunter BJ. Health Hazard Evaluation Report. *National Institute for Occupational Health (NIOSH) No. 88-101-208*. 1990.
11. Association of Operating Room Nurses. *Standards, Recommended Practices & Guidelines*. Association of Operating Room Nurses, Inc.: Denver 2000. Pp 239, 251, 290, 291.
12. OSHA Preambles Air Contaminants (29 CFR 1910.1000) VI. Health Effects Discussion and Determination of Final PEL.
13. OSHA Regulations (Standards - 29 CFR) Substance safety data sheet, Benzene - 1910.1028 App A.
14. Gatti, Murphy JB, Noone RB. Analysis of electrocautery smoke produced during reduction mammoplasty. *Surg Forum*. 1986; 37:579-80.
15. Bryant C, Gorman R, Stewart J, Whong WZ. Health Hazard Evaluation Report; HETA 85-126-1932; Hazard Evaluations and Technical Assistance Branch. *NIOSH Publications*. 1988.
16. Esper E. Transperitoneal absorption of thermocautery-induced carbon monoxide formation during laparoscopic cholecystectomy. *Surg Laparosc Endosc*. 4(5):333-5. 1994.
17. Ott DE. Laser smoke and hemoglobin oxidation at laparoscopy [abstr.]. *Laser Surg Med*. 1994; 6:17.
18. Wu JS, Monk T, Luttmann DR, Meiniger TA, Soper NJ. Production and systemic absorption of toxic byproducts of tissue combustion during laparoscopic cholecystectomy. *J Gastro. Surg*. 1998; 2(5):399-405.
19. Wu JS, Luttmann DR, Meiniger TA, Soper NJ. Production and systemic absorption of toxic byproducts of tissue combustion during laparoscopic surgery. *Surg Endosc*. 1997; 11(11):1075-9.
20. Beebe DS, Swica H, Carlson N, Palahniuk RJ, Goodale RL. High levels of carbon monoxide are produced by electro-cautery of tissue during laparoscopic cholecystectomy. *Anesth Analg*. 1993; 77(2):338-41.
21. OSHA Regulations (Standards - 29 CFR) Substance technical guidelines for formalin - 1910.1048 App A.
22. Surgical Smoke Evacuation Systems. *Health Devices*. 1997; 26(4):132-72.
23. Hensman C, Newman EL, Shimi SM, Cuschieri A. Cytotoxicity of electro-surgical smoke produced in an anoxic environment. *Am J Surg*. 1998; 175(3):240-1.
24. Gatti JE, Bryant CJ, Noone RB, Murphy JB. The mutagenicity of electrocautery smoke. *Plast Reconstr Surg*. 1992; 89(5):781-6.
25. Tomita Y, Mihashi S, Nagata K, Ueda S, Fujiki M, Hirano M, Hirohata T. Mutagenicity of smoke condensation induced by CO<sub>2</sub>-laser irradiation and electrocauterization. *Mutat Res*. 1981; 89:145.
26. Runyon BA. Surgical peritonitis and other diseases of the peritoneum, mesentery, omentum and diaphragm. In: Sleisenger MH, Fordtran JS, eds. *Gastrointestinal Disease*. WB Saunders: Philadelphia. 1993.
27. Shear L, Swartz C, Shinaberger JA, Barry KG. Kinetics of peritoneal fluid absorption in adult man. *N Engl J Med*. 1965; 272:123-7.
28. Lill SR, Parsons RH, Bubac I. Permeability of the diaphragm and fluid resorption from the peritoneal cavity in the rat. *Gastroenterology*. 1979; 76:997-1001.
29. Tsilibary EC, Wissig SL. Absorption from the peritoneal cavity: SEM study of the mesothelium covering the peritoneal surface of the muscular portion of the diaphragm. *Am J Anat*. 1977; 149:127-33.
30. Zink J, Greenway CV. Control of ascites absorption in anesthetized cats: effects of intraperitoneal pressure, protein, and furosemide diuresis. *Gastroenterology*. 1977; 73:1119-24. Johnson GK, Robinson WS. Human immunodeficiency virus-1 (HIV-1) in the vapors of surgical power instruments. *J Med Virol*. 1991; 33(1):47-50.
31. Ott DE. Laparoscopic surgical smoke absorbed into bloodstream. *O R Manager*. 1994; 10:19.
32. Nezhat C, Seidman DS, Vreman HJ, Stevenson DK, Nezhat F, Nezhat C. The risk of carbon monoxide poisoning after prolonged laparoscopic surgery. *Obstetrics and Gynecology*. 1996; 88(5):771-4.
33. Johnson GK, Robinson WS. Human immunodeficiency virus-1 (HIV-1) in the vapors of surgical power instruments. *J Med Virol*. 1991; 33(1):47-50.
34. Abramson AL, DiLorenzo TP, Steinberg BM. Is papillomavirus detectable in the plume of laser-treated laryngeal papilloma? *Arch Otolaryngol Head Neck Surg*. 1990; 116(5):604-7.
35. Baggish MS, Polesz BJ, Joret D, Williamson P, Refai A. Presence of human immunodeficiency virus DNA in laser smoke. *Lasers Surg Med*. 1991; 11(3):197-203.
36. Sawchuk WS, Weber PJ, Lowy DR, Dzubow LM. Infectious papillomavirus in the vapor of warts treated with carbon dioxide laser or electrocoagulation: detection and protection. *J Am Acad Dermatol*. 1989; 21(1):41-9.
37. Matchette LS, Vegella TJ, Faalan RW. Viable bacteriophage in CO<sub>2</sub> laser plume: aerodynamic size distribution. *Laser Surg Med*. 1993; 13(1):18-22.
38. Walker NPJ, Matthews J, Newsom SWB. Possible hazards from irradiation with the carbon dioxide laser. *Lasers in Surgery and Medicine*. 1986; 6:84-6.
39. Ziegler BL, Thomas CA, Meir T, Muller R, Fliedner TM, Weber L. Generation of infectious retrovirus aerosol through medical laser irradiation. *Lasers Surg Med*. 1998; 22(1):37-41.
40. Garden JM, O'Banion MK, Shelnitz LS, Pinski KS, Bakus AD, Reichmann ME, Sundberg JP. Pappillomavirus in the vapor of carbon dioxide laser - treated verrucae. *Clin Inves*. 1988; 259(8):1199-1202.
41. Gloster H, Roenigk R. Risk of acquiring human papillomavirus from the plume produced by the carbon dioxide laser in the treatment of warts. *J Am Acad Dermatol*. 1995; 32(3):436-41.
42. Hallmo P, Naess O. Laryngeal papillomatosis with human papillomavirus DNA contracted by a laser surgeon. *Eur Arch Otolaryngol*. 1991; 248:425-7.
43. Nezhat C, Winer WK, Nezhat F, Nezhat C, Forrest D, Reeves WG. Smoke from laser surgery: Is there a health hazard. *Surg Med*. 1987; 7:376-82.
44. Champault G, Taffinder N, Zioli M, Riskalla H, Catheline JMC. Cells are present in the smoke created during laparoscopic surgery. *British Journal of Surgery*. 1996; 84:993-5.
45. DesCouteaux JG, Picard P, Poulin EC, Baril M. Preliminary study of electrocautery smoke particles produced in vitro and during laparoscopic procedures. *Surg Endosc*. 1996; 19:152-8.

46. Heinsohn P, Jewett DL, Balzer L, Bennett CH, Seipel P, Rosen A. Aerosols created by some surgical power tools: Particle size distribution and qualitative hemoglobin content. *Applied Occupational Environ Hyg.* 1991; 6(9):773-6.
47. Fletcher JN, Mew D, DesCoteaux JG. Dissemination of melanoma cells within electrocautery plume. *Am J Surg.* 1999; 178(1):57-9.
48. Nduka CC, Poland N, Kennedy M, Dye J, Darzi A. Does the ultrasonically activated scalpel release viable airborne cancer cells? *Surg Endosc.* 1998; 12(8):1031-4.
49. Oosterhuis JW, Verschueren RCJ, Eibergen R, Oldhoff J. The viability of cells in the waste products of CO<sub>2</sub>-laser evaporation of Cloudman mouse melanomas. *Cancer.* 1982; 49(1):61-7.
50. Cavina E, Goletti O, Molea N, Bucciatti P, Chiarugi M, Boni G, Lazzeri E, Bianchi R. Trocar site tumor recurrences. *Surg Endosc.* 1998; 12:1294-6.
51. Kim SH et al. Does laparoscopic vs. conventional surgery increase exfoliated cancer cells in the peritoneal cavity during resection for colorectal cancer? *Surg Endosc* 1999; 13:821.
52. Lee SW, Gleason NR, Bessler M, Whelan RL. Peritoneal irrigation with povidone-iodine solution after laparoscopic-assisted splenectomy significantly decreases port-tumor recurrence in a murine model. *Dis Colon Rectum.* 1999; 42(3):319-26.
53. Martinez J, Targorona EM, Balague C, Pera M, Trias M. Port site metastasis. An unresolved problem in laparoscopic surgery. *Int Surg.* 1995; 80(4):315-21.
54. Savalgi RS. Port-site metastasis in the abdominal wall: fact or fiction? *Semin Surg Oncol.* 1998; 15(3):189-93.
55. Texler ML, King G, Hewett PJ. From inside out: microperforation of the gallbladder during laparoscopic surgery may liberate mucosal cells. *Surg Endosc.* 1998; 12:1297-9.
56. Wang PH, Yuan CC, Lin G, Ng HT, Chao HT. Risk factors contributing to early occurrence of port site metastases of laparoscopic surgery for malignancy. *Gynecol Oncol.* 1999; 72(1):38-44.
57. Kazemier. Port site metastases after laparoscopic colorectal surgery for cure of malignancy. *Br J Surg.* 1995; 82:1141-2.
58. Nduka CC. Abdominal wall metastases following laparoscopy. *Br J Surg.* 1994; 81:648-52.
59. Lapple CE. Particle Technology... the little things in life. *Stanford Res Inst J.* 1961; 3rd Quarter.
60. Alberti PW. The complications of CO<sub>2</sub> Laser surgery in otolaryngology. *Acta Otolaryngol (Stockh).* 1981; 91:375-81.
61. Baggish MS, Elbakry M. The effects of laser smoke on the lungs of rats. *Am J Obstet Gynecol.* 1987; 156(5):1260-5.
62. Wenig BL, Stenson KM, Wenig BM, Tracey D. Effects of plume produced by the Nd:YAG laser and electrocautery on the respiratory system. *Lasers Surg Med.* 1993; 13(2):242-5.
63. Wehner AP. Deffects of inhaled asbestos, asbestos plus cigarette asbestocement and talc powder in hamsters. *IARC Sci Publ.* 1980; 30:373-6.
64. Rogers WR, McCullough, Caton JE. Cigarette smoking by baboons: in vivo assessment of particulate inhalation using bronchoalveolar lavage to recover [14C] doctriacontane. *Toxicology.* 1981; 20:309-21.
65. Chung A and Wiggs B. Mineral particles, mineral fibers, and lung cancer. *Environ Res.* 37:364-72. 1985.
66. Hoidal JR, Niewoehner DE. Lung phagocyte recruitment and metabolic alterations induced by cigarette smoke in humans and hamsters. *Am Rev Respir Dis.* 1982; 126:548-52.
67. Hinds W, First MW, Huber GL, Shea JW. A method for measuring respiratory deposition of cigarette smoke during smoking. *Am Ind Hyg Assoc J.* 1983; 44:113-8.
68. McLeod R, Mack DG, McLeod EG, Campbell EJ, Estes RG. Alveolar macrophage function and inflammatory stimuli in smokers with and without obstructive lung disease. *Am Rev Respir Dis.* 1985; 131:377-84.
69. Phelps DW, Veal JT, Buschbom RL, Filipy RE, Wehner AP. Tobacco smoke inhalation studies: a disimetric comparison of different cigarette types. *Arch Environ Health.* 1984; 39:359-63.
70. OSHA website on laser and electrosurgery plume <http://www.osha-slc.gov/SLTC/laserelectrosurgeryplume/index.html>
71. Occupational Safety and Health Act of 1970, Duties Section 5(a)(1).
72. OSHA Regulations (Standards - 29 CFR); Respiratory Protection. - 1910.134; section 1(a)
73. OSHA Regulations (Standards - 29 CFR); Bloodborne pathogens. - 1910.1030; section d(3)(l)
74. Ulmer B. Report of OSHA's draft: Information for health care workers exposed to laser and electrosurgery smoke. *Today's Surg Nurse.* 1999; 21(2):18-9.
75. American National Standard for the Safe Use of Lasers in Health Care Facilities (ANSI Z136.3).
76. Romig CL, Smalley PJ. Regulation of Surgical Smoke Plume. *AORN J.* 1997; 65(4):824-8.
77. Control of smoke from laser/electric surgical procedures. *DHHS (NIOSH) Pub.* 96-128. 1996.
78. Chen CC, Willeke K. Aerosol penetration through surgical masks. *Am J Infect Control.* 1992; 20:177-184.
79. Chen SK, Vesely D, Brosseau LM, Vincent JH. Evaluation of Single-use masks and respirators for protection of health care workers against mycobacterial aerosols. *Amer J Inf Control.* 1994; 22:65-74.
80. Redmayne AC, Wake D, Brown RC, Crook B. Measurement of the degree of protection afforded by respiratory protective equipment against microbiological aerosols. *Ann Occup Hyg.* 1997; 41(1):636-40.
81. Crook B, Brown RC, Wake D, Redmayne AC. Final report to HSE: efficiency of respiratory protective equipment against microbiological aerosols. *Sheffield: HSL Report.* 1996; 31. IR/L/M/96/05.
82. Tseng LN, Berends FJ, Wittich, Bouvy ND, Marquet RL, Kazemier G, Bonjer HJ. Port-site metastases. Impact of local tissue trauma and gas leakage. *Surg Endosc.* 1998; 12(1):1377-80.
83. Ott DE, Moss E, Martinez K. Aerosol Exposure from an ultrasonically activated (harmonic) device. *J Am Assoc Gyn Lap.* 1998;5(1):29-32.

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