

Status of Surgical Smoke:

Risks, Remediation and Regulation

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Introduction

Electrosurgery devices, laser ablation and ultrasonic scalpels are widely recognized as major advances in surgical technology; they are the tools of minimally invasive surgery, by far the fastest-growing operative procedure. Electrosurgery is used in more than 85% of 24 million surgeries performed annually in the U.S.¹ These techniques, however, intentionally destroy human tissue, which creates a gaseous byproduct commonly referred to as surgical smoke or plume. Each year, an estimated 500,000 healthcare workers – including surgeons, nurses, anesthesiologists and surgical technologists – are exposed to these gases, with potentially quite serious repercussions.² The precise cause and effect aren't fully known, but perioperative nurses have twice the incidence of many respiratory problems as compared with the general population.³

More than 150 different chemical constituents have been identified in surgical smoke, some with the capacity for causing human cell damage, cancer and infectious disease.⁴ Representative chemicals found in electrosurgical smoke are listed in Table 1. Although these gases appear in trace amounts in surgical smoke, OR staff inhale them for several hours per day over long periods of time, which is likely to have cumulative effect. Also, smoke can and does interfere with the surgeon's ability to see the surgical field, which may delay or prolong surgical procedures. If nothing else, the acrid smell of superheated tissue permeates the surgery suite, making for an unpleasant workplace experience.

Table 1: Chemicals Found in Electrosurgical Smoke

Acetonitrile	Furfural (aldehyde)
Acetylene	Hexadecanoic acid
Acrolein	Hydrogen cyanide
Acrylonitrile	Indole (amine)
Alkyl benzene	Isobutene
Benzaldehyde	Methane
Benzene	3-Methyl butenal (aldehyde)
Benzonitrile	6-Methyl indole (amine)
Butadiene	4-Methyl phenol
Butene	2-Methyl propanol
3-Butenenitrile	Methyl pyrazine
Carbon monoxide	Phenol
Creosol	Propene
1-Decene (hydrocarbon)	2-Propylene nitrile
2,3 – Dihydro indene (hydrocarbon)	Pyridine
Ethane	Pyrrole (amine)
Ethene	Styrene
Ethylene	Toluene (hydrocarbon)
Ethyl benzene	1-Undecene (hydrocarbon)
Ethynyl benzene	Xylene
Formaldehyde	

Source: Barrett WL, "Surgical smoke – a review of the literature," Surgical Endoscopy, 2003

Much more research is needed to assess the true nature of the health hazards posed by surgical smoke, but failure to reduce the threat appears to be a risky proposition.

Smoke evacuation devices have been shown to be effective in limiting exposure to the noxious odor and potential health hazards of smoke and plume. These devices have not been used on a routine and consistent basis in many ORs, in spite of a recommendation from the Association of periOperative Registered Nurses (AORN) that smoke evacuation systems and wall suction with an in-line ultralow penetration air (ULPA) filter be used.⁵ Education and leadership are needed to adopt smoke evacuation technology and assure its routine use. In addition, many cite the lack of sufficient regulation as a cause of low adoption.

Risks

A comprehensive literature review found little difference in the health risks of laser plume and electrosurgical smoke, though some studies suggest electrosurgical smoke might pose a greater risk, particularly if these risks are quantified on a time-weighted basis that takes into account accumulation over long periods of exposure.⁶

A 2002 study found that surgical smoke particles can travel at about 40 miles per hour.⁷ When an electrosurgical unit is activated, the concentration of the particles can rise from 60,000 particles/cubic feet to over 1 million particles/cubic feet. Adding to this concern is the fact that every surgical suite must have an air exchange of at least 15 times per hour; therefore, surgical smoke particles get caught up on these air currents and become evenly distributed throughout the OR.

A 1981 Japanese study found that 77% of the particles within surgical smoke are less than 1.1 microns in size.⁸ Inhaled particles of this size can easily be deposited in the alveoli, the gas exchange regions of the lungs, which can lead to respiratory problems. Circulating blood will pick up whatever is in the alveoli and distribute it randomly throughout the body. A standard surgical mask filters particles in excess of 5 microns in size and thus is ineffective against smaller particles when used during procedures not employing proper smoke evacuation practices.

In a study conducted in 1992, Dr. John E. Gatti, an assistant clinical professor of surgery at the University of Medicine and Dentistry of New Jersey, and colleagues reported on the mutagenicity of surgical smoke.⁹ Surgical smoke samples were collected during two breast reduction surgeries. The heat destruction of tissue with electrosurgery resulted in smoke containing hydrogen cyanide, butadiene, acetylene, ammonia and formaldehyde.

The researchers also noted that the smoke particles were unstable and lost their mutagenic potential within two hours after collection. While admitting their results could not conclusively determine a serious health risk to surgical personnel who are regularly exposed to surgical smoke, Gatti, et al proposed that attempts to minimize exposure were certainly in order.

A 1993 study detailed the effects of exposure to electrosurgical smoke and laser plume on the respiratory system of animal subjects.¹⁰ Of notable concern were the changes seen in lung pathology of the lab rats used in the study. The researchers reported the development of blood vessel hypertrophy, alveolar congestion and emphysematous changes.

In 1999 Dr. John N. Fletcher of the University of Calgary, Alberta, and colleagues reported that electrosurgical smoke was a vehicle for transplanting malignant cells to benign tissue.¹¹ The observed occurrence of port site metastasis after laparoscopic resection of colon tumors led investigators to believe that the smoke might contain viable malignant cells after cauterization of the tumor. The research indeed discovered intact, viable melanoma cells in significant quantities in the surgical smoke. Furthermore, the cells present immediately after collection remained viable for five to seven days under laboratory conditions.

The potential for the transmission of viable organisms within surgical smoke is great. In a 1991 study, a 44-year old surgeon, who rarely evacuated the surgical smoke when using the laser to vaporize condyloma, developed laryngeal papillomatosis. When his lesions were biopsied, the same type of virus was identified that is found in anogenital warts, which are not normally found in the throat.

More recently, in 2011 surgical smoke from electrocauterization in plastic surgery was analyzed at a British operating room over a two-month period. On average the smoke produced daily was equivalent to that produced by the smoking of 27-30 cigarettes.¹²

Research has also noted that longtime exposure to fine particulate air pollution is associated with the increased incidence of cardiovascular disease and death among postmenopausal women.¹³ Since AORN now reports the average age of a perioperative RN is 53, that finding is a major concern for those women inhaling surgical smoke on a regular basis.¹⁴

Remediation

There are a number of surgical smoke evacuation systems in use, which can be broken down into stationary and portable systems.

Stationary systems are integrated into the facility in that the piping is built into the walls. OR personnel control suction, and smoke is filtered through a HEPA filter and eliminated in a facility away from the operating theater. Alternatively, all components can be housed in the OR.

Stationary systems can also preserve floor and cart space and eliminate cable clutter, since the control unit mounts on the wall or integrates into the surgical boom.

Portable systems house the control, suction, filtration and exhaust components in one unit. They can mount on a cart, table or wall. Some units are quite compact and, despite their small size, are just as effective as stationary units.

Modern systems are quieter and more streamlined, making them easier to use than ever before. The cost has come down considerably, and many do not interfere at all with the operative field. For example, there are several smoke evacuation devices available for laparoscopic procedures, including passive systems connected to a trocar sleeve that provide ventilation for air movement to disperse the surgical smoke and active systems that remove the plume throughout the entire procedure. Some are integrated right into the surgical tool, such as an electrosurgery or electrocautery pencil.

This evolution in ease of use makes the slow adoption of smoke evacuation technology hard to understand. In 2012 the *AORN Journal* published a study of current and past surgical smoke practices, based on a 2010 survey of 1,356 active members of AORN. It assessed the level of compliance with established surgical smoke control measures (wall suction, portable evacuator, approved respirators) in various medical specialties and facilities throughout North America, as well as the extent to which compliance rates changed from a 2007 survey.¹⁵ The study found that while the use of wall suction as a control measure had increased for nearly all procedures, progress in the adoption of other control measures has been mixed, with improvement for some procedures, no change for most procedures and a decrease in compliance for a few procedures.

As shown in Table 2, survey respondents in both 2007 and 2010 indicated a higher frequency of smoke evacuator use during laser procedures than during the comparable electrosurgery and ultrasonic scalpel procedures.¹⁵ For example, in 2010, for condyloma or dysplasia treatment (the category with the highest indicated smoke evacuation use), 84% of respondents indicated they used smoke evacuators “always” or “often” during laser ablation but only 68% used smoke evacuators during electrosurgery and ultrasonic scalpel procedures.

Table 2. Reported Frequency of “Often or “Always for Smoke Evacuator Use

Procedure type	Wall suction				P	Smoke evacuator				P
	2007		2010			2007		2010		
	Frequency	Percentage*	Frequency	Percentage*		Frequency	Percentage*	Frequency	Percentage*	
Electrosurgery, electrocautery, diathermy										
■ Condyloma or dysplasia treatment	249	67	591	75	< .001	239	59	598	68	< .001
■ Cosmetic/plastic surgery	263	68	649	77	< .001	67	20	176	24	.015
■ Vascular skin lesion removal	209	63	558	76	< .001	28	11	74	12	.15
■ Malignant skin lesion removal	263	62	658	74	< .001	32	10	102	14	< .001
■ Benign skin lesion removal	257	61	665	72	< .001	25	8	78	11	.005
■ Standard (nonlaser) surgery	352	64	928	76	< .001	35	8	130	13	< .001
■ Other procedures	282	65	727	76	< .001	35	10	95	12	.04
Laser										
■ Condyloma or dysplasia ablation	177	62	452	71	< .001	345	83	671	84	.74
■ Other carbon dioxide laser procedures	143	61	365	67	.004	232	75	488	74	.37
■ Carbon dioxide laser tissue resection	152	66	372	70	.02	243	75	507	77	.31
■ Other laser procedures	82	57	261	65	.002	101	61	235	53	< .001
■ Nd:YAG laser tissue resection	77	54	179	60	.03	93	56	165	53	.26
■ Other Nd:YAG laser procedures	61	46	161	54	.005	81	55	135	45	< .001
■ Cosmetic/plastic surgery	154	70	394	75	.005	87	39	194	40	.69
■ Malignant skin lesion removal	149	59	404	74	< .001	71	31	145	30	.77
■ Vascular skin lesion removal	124	61	291	69	< .001	56	31	291	31	.81
■ Benign skin lesion removal	159	60	405	71	< .001	68	29	136	28	.71
■ Hair removal	7	23	14	19	.37	7	22	18	29	.20
■ Endoscopy/bronchoscopy	190	75	463	83	< .001	40	19	83	18	.40
■ Laparoscopy/arthroscopy	227	64	594	80	< .001	52	18	150	23	< .001
■ LASIK	7	23	25	27	.35	5	17	11	16	.77
Ultrasonic scalpel										
■ All ultrasonic scalpel procedures	277	63	727	76	< .001	25	7	86	11	< .001

LEV – local exhaust ventilation.
 * Because there were a different number of responses for each procedure type, the percentage values reflect the fraction of responses for each procedure type rather than the total number of survey respondents.

Source: Edwards, BE, and Reiman RE, “Comparison of Current and Past Surgical Smoke Control Practices,” *AORN Journal*, March 2012

Of the 1,356 people who participated in the survey, 210 chose to enter comments. Of these, 49 specified obstacles to compliance with established surgical smoke control practices at their facility.

The most commonly reported obstacle was surgeons' resistance or refusal to allow the use of smoke evacuators. Other reported obstacles were cost of the devices, bulkiness and excessive noise. Six respondents indicated that a clear regulation (such as an Occupational Safety and Health Administration [OSHA] standard requiring smoke evacuation use) was the only thing that would overcome resistance at their facility.

Another research study was conducted in 2010 by former AORN President and nursing professor Kay Ball, PhD, RN, to identify the key indicators of compliance with smoke evacuation recommendations during electrosurgical procedures.¹⁶ She found the most significant indicator was education; if nurses were provided information about the hazards of surgical smoke exposure, they were more apt to comply with smoke evacuation recommendations. Also significant to compliance was having strong leadership that supported smoke evacuation practices, having easy to follow policies on smoke evacuation, and promoting regular internal collaboration (physicians and nurses working together to ensure all smoke is evacuated).

"A first step in developing a smoke evacuation program is to make the commitment as a facility that protecting patients and staff from the potentially harmful effects of surgical smoke is a priority," Ball wrote. "The commitment should be made with representatives from each of the professional groups providing care in the operating room: surgeons, anesthesia care providers, perioperative staff and administration. Agreement from the entire surgical team before the program begins is important and will help ensure success. Once an agreement and commitment have been reached, a plan should be developed to introduce the program through education."

Surgeon Leonard Schultz, MD, FACS, wrote in the *AORN Journal* in February 2014 that many surgeons dismiss the risks of smoke inhalation and won't allow the use of smoke evacuation devices during procedures.¹⁷ He cites a number of factors, including:

- Concern that an altered protocol could negatively affect the surgical result
- Anxiety associated with any change to routines
- A lack of knowledge about sources that recommend the removal of smoke
- A lack of enthusiasm for smoke removal on the part of administrators or nursing personnel
- Distraction caused by the noise generated by the smoke evacuator
- Unavailability of devices that achieve high efficiency capture
- Devices that require the surgeon's involvement

"All of these factors can be overcome by education, use of quieter smoke evacuators, and use of capture devices that remove smoke without requiring staff members to set them up," he wrote. "After educators and vendors present educational material to surgeons and other perioperative personnel, they often become strong advocates of the use of smoke evacuation."

Regulations/Recommendations

A number of standards organizations and agencies have weighed in on surgical smoke evacuation. Many organizations and agencies are making their recommendations more powerful with changing the verb from “should” to “shall.” For example, the American National Standards Institute states that airborne contaminants from laser surgery shall be controlled and that the electrosurgical device produces the same type of airborne contaminants as lasers do.¹⁸

However, there are as yet no current national standards with the force of governmental regulation. Under the Occupational Safety and Health Act of 1970, Employee Safety Standards (General Duty, Section 5A-1), comes as close to a regulation as any other entity. This duty states “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.”²

OSHA’s respiratory protection recognizes that laser plume and electrosurgical smoke contain toxic, mutagenic and carcinogenic elements.² OSHA also mandates and identifies the removal of atmospheric contaminants with acceptable engineering controls and local ventilation, including smoke evacuation systems.

The National Institute of Occupational Safety and Health (NIOSH) is part of the Centers for Disease Control and Prevention in the U.S. Department of Health and Human Services. NIOSH investigates potential occupational health risks and makes recommendations to OSHA. The recommendations of NIOSH are referenced on the OSHA website on smoke evacuation. The NIOSH Hazard Control Alert on the Control of Smoke From Laser/Electric Surgical Procedures recommends evacuation and filtration of surgical smoke.¹⁹ It specifies that a smoke evacuator or room suction hose nozzle inlet must be kept within 2 inches of the surgical site and the smoke evacuator should be activated at all times when plume is present.

ECRI, formerly the Emergency Care Research Institute, a nonprofit agency in Plymouth Meeting, Pa., recommends that it is prudent to evacuate surgical smoke, and that there is no difference between smoke produced by lasers and smoke produced by electrosurgery units.²⁰

The Joint Commission also recommends that surgical smoke be filtered and evacuated through the use of room ventilation and smoke evacuation methods.²¹

Conclusion

Surgical smoke carries the strong potential of long-term health damage from repeated exposure. The notion that it is akin to the effects of intense second-hand cigarette smoke should itself be of concern to medical personnel. There are risks of infectious disease as well.

The fact that there are relatively inexpensive and readily available devices to remove all or most of these harmful gases suggests that action needs to be taken.

This is why education is essential to drive widespread adoption and use of smoke evacuation technology. Physicians and nurse leaders are receptive to data and informed arguments in favor of greater safety in their work areas.

Longitudinal, multi-center studies are needed on the long-term health effects of inhalation of surgical smoke, which penetrates surgical masks and even respirators with fine particulates.

Surgical smoke is one of those elements of daily life in the hospital that are not well understood. Many clinicians take pride in handling the smoky, messy work of surgery with self-confidence. And yet, obscured in the smoke around this issue is a very serious risk to those who take such pride in assessing and addressing health risks affecting their patients.

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