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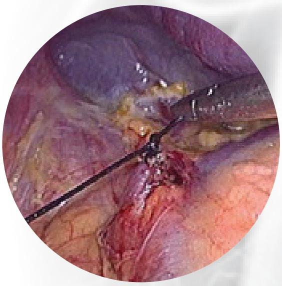
Laparoscopic Smoke Plume:

Challenges and Solutions for Surgeons, Staff and Patients



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Laparoscopic Smoke Plume: Challenges and Solutions for Surgeons, Staff and Patients

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Welcome to

LAPAROSCOPIC SMOKE PLUME: CHALLENGES AND SOLUTIONS FOR SURGEONS, STAFF AND PATIENTS

(A Continuing Education Self-Study Activity)

CONTINUING EDUCATION INSTRUCTIONS

This educational activity is intended for use as a stand alone self-study activity. We suggest you take the following steps for successful completion:

1. Read the overview and objectives to ensure consistency with your own learning needs and objectives.
2. Review the content of the self-study activity, paying particular attention to those areas that reflect the objectives.
3. Complete the Test Questions and compare your responses with the answers provided.
4. For additional information on an issue or topic, consult the references.
5. To receive credit for this activity complete the evaluation and registration form.
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Pfiedler Enterprises

2101 S. Blackhawk Street, Suite 220
Aurora, CO 80014-1475
Phone: 720-748-6144
Fax: 720-748-6196
Website: www.pfiedlerenterprises.com

OVERVIEW

Over the past several decades, laparoscopic techniques facilitated by the use of electrosurgery and other energy modalities have been developed to enable more advanced procedures to be performed through smaller and less traumatic incisions, thus providing exciting new treatment options for many patients. The benefits of laparoscopic surgery using various energy modalities (reductions in blood loss, postoperative pain, and lengths of stay) are well-documented. However, as the number and types of laparoscopic procedures increase, there is a corresponding increase in exposure to smoke plume generated during these procedures, which poses certain health risks to members of the surgical team as well as the patient. Smoke plume generated from electrosurgery or laser use has been found to contain toxic gases and vapors, bioaerosols, and viruses, all of which in high concentrations can cause adverse health conditions. The purpose of this continuing education activity is to review the challenges associated with laparoscopic smoke plume as well as solutions to minimize staff and patient exposure. The contents of surgical smoke plume, as well as key considerations of smoke production during laparoscopic procedures, will be reviewed. The hazards of exposure to smoke plume for healthcare workers and patients will be discussed. Solutions to minimize the risk of exposure to laparoscopic smoke plume will be presented. Finally, key criteria in the evaluation and selection of a smoke evacuation system for laparoscopic procedures will be explored.

OBJECTIVES

After completing this continuing nursing education activity, the participant should be able to:

1. Define surgical smoke plume.
2. Identify the hazards related to laparoscopic smoke plume for the surgeon, staff and patient.
3. Discuss solutions to reduce the risk of the hazards associated with laparoscopic smoke plume.
4. Describe the selection criteria for smoke evacuation systems for laparoscopic procedures.

INTENDED AUDIENCE

This continuing education activity is intended for use by perioperative registered nurses who are involved in the care of patients undergoing laparoscopic surgery and who are interested in learning more about the challenges of laparoscopic surgical smoke plume and effective solutions to reduce the associated hazards for surgeons, staff, and patients.

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PLANNING COMMITTEE

Elizabeth Deroian, RN, BA — **Aurora, CO**
Program Manager
Pfiedler Enterprises

Rose Moss, RN, MN, CNOR — **Hendersonville, NC**
Nurse Consultant

EXPERT REVIEWERS

Julia A. Kneedler, RN, MS, EdD — **Aurora, CO**
Director of Education
Pfiedler Enterprises

Judith Pfister, RN, BSN, MBA — **Aurora, CO**
Program Manager
Pfiedler Enterprises

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Elizabeth Deroian, RN, BA

1. Yes
2. Employed by company that receives grant funds from **CooperSurgical, Inc.**
3. No

Rose Moss, RN, MN, CNOR

1. No
2. None
3. No

Julia A. Kneedler, RN, MS, EdD

1. Yes
2. Employed by company that receives grant funds from **CooperSurgical, Inc.**
3. No

Judith Pfister, RN, BSN, MBA

1. Yes
2. Employed by company that receives grant funds from **CooperSurgical, Inc.**
3. No

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Phone:	720-748-6144
Email:	tonia@pfiedlerenterprises.com
Postal Address:	2101 S. Blackhawk Street, Suite 220 Aurora, Colorado 80014
Website URL:	http://www.pfiedlerenterprises.com

INTRODUCTION

Laparoscopic minimally invasive surgery is one of the most important technological advances of the past two decades, indicated by its widespread acceptance and ongoing development.[1] Laparoscopic techniques, facilitated by the use of electrosurgery or laser, have been developed to enable performance of some of the most advanced operative procedures through ever smaller and less traumatic incisions. As a result, both the number and types of procedures performed laparoscopically in the United States increase every year (see Table 1).[2] However, in addition to the expanded treatment options and recognized benefits, the rise in the number and types of laparoscopic procedures and techniques is accompanied by a corresponding increase in the associated risk of exposure to smoke plume.

Table 1 - Number and Types of Laparoscopic Procedures Performed Annually in the United States[3]

Type of Procedure	Total Procedures	Number (%) Performed Laparoscopically
General Surgery Procedures:		
Cholecystectomy	1,084,882	922,150 (85%)
Adhesiolysis	215,760	155,347 (72%)
Hernia repair	820,191	114,827 (14%)
Appendectomies	334,388	73,565 (22%)
Nissen fundoplication	47,087	44,733 (95%)
Colon resection	380,000	26,600 (7%)
Gynecology Procedures:		
Adnexa removal	350,059	227,538 (65%)
Sterilization	684,000	342,000 (50%)
Hysterectomies	582,000	87,300 (15%)
Myomectomy	64,977	45,484 (70%)
Urology Procedures:		
Pelvic floor reconstruction	160,000	64,000 (40%)
Total:	**4,723,344**	**2,103,544**

SURGICAL SMOKE PLUME

Overview

The term smoke is used to describe any gaseous by-product that contains bioaerosols, including viable and non-viable cellular material.[4] Throughout the medical literature, the terms smoke, plume and, at times, aerosol are used to describe the product of electrosurgery and laser tissue ablation. The qualities of surgical smoke produced by these two methods are very similar. Furthermore, both electrosurgery and laser systems generate surgical smoke plume by the same mechanism: during the procedure (i.e., cutting, coagulating, vaporizing or ablating tissue), the target cells are heated to the point of boiling, causing the membranes to rupture and disperse fine particles into the air or pneumoperitoneum in the case of laparoscopic procedures. The by-product that results from the use of ultrasonic scalpels is frequently referred to as plume, aerosol, or vapor. With the use of ultrasonic energy, aerosols are produced without a heating (i.e., burning) process, which is generally referred to as low-temperature vaporization. However, this low-temperature vapor generally has a higher chance of carrying viable and infectious particles than higher temperature aerosols.

During laparoscopic procedures, the peritoneal cavity fills with smoke and can obscure the surgeon's field of view.[5] While this is annoying to many surgeons, it also serves to delay the procedure, i.e., insufflation gas flow must be attended to in order to allow for dissipation of the smoke before surgery can resume. By minimizing the visual obstruction due to surgical smoke, procedure time and thereby OR time is reduced, which in turn can improve OR efficiency and decrease the associated costs. In addition, laparoscopic surgery presents a unique challenge for smoke evacuation: surgical smoke and aerosols should be regularly evacuated from the peritoneum in order to avoid harming the patient; on the other hand, upon release of the pneumoperitoneum, the escaping vapor should be filtered in order to protect the surgical team. This will be discussed in greater detail later in this study guide.

Particle Size

Surgical smoke consists of 95% water, steam, and gaseous by-products and 5% cellular debris in the form of particulate matter. The gaseous component produces the noxious odor, while the particulate matter is composed of chemicals, blood and tissue particles, viruses, and bacteria.[6] The various types of heat-producing devices used in surgery produce a different size particle; this is important to note because the smaller the particle size, the farther it can travel to affect the nonscrubbed surgical team members as well as those who are scrubbed. Particles that remain airborne are smaller than 100 micrometers in diameter; particles that are 5 micrometers or larger are deposited on the walls of the nose, pharynx, trachea, and bronchus; those that are smaller than 2 micrometers are deposited in the bronchioles and alveoli. In comparison, the thickness of an average human hair is 200 micrometers. See Table 2 for the particle size produced by various heat-producing devices in the OR.

Table 2 - Particle Size for Heat-Producing Devices in the OR

Device	Mean Aerodynamic Particle Size (micrometers)
Electrosurgical Unit	0.07
Laser	0.31
Ultrasonic Scalpel	0.35-6.5

Chemical Composition of Surgical Smoke Plume

Since the mid-1970s, the body of evidence documenting the hazardous components of surgical smoke has continued to grow and the chemical composition of surgical smoke has been well-documented (see Table 3).[7] Surgical smoke can contain chemical by-products similar to other smoke plumes (e.g., cigarette smoke), including benzene, carbon monoxide (CO), formaldehyde, hydrogen cyanide, methane, phenol, styrene, and toluene; these by-products also are known to be carcinogenic. The concentration of these by-products produced during pyrolysis depends on the type of tissue, power density, and length of time the energy is used on the tissue.

Table 3 - Chemical Contents of Surgical Smoke[8]

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

HAZARDS RELATED TO LAPAROSCOPIC SMOKE PLUME FOR THE SURGEON, STAFF, AND PATIENT

Overview

As noted, surgical smoke has been found to contain toxic gases, vapors, bioaerosols, and viruses, all of which can cause adverse health conditions. Personnel working in the operating room have been exposed to surgical smoke for many years; in the past, they may have been unaware that it may lead to certain health risks not only for them, but for their patients as well. Every year, it is estimated that 500,000 health-care workers, including surgeons, nurses, anesthesia providers, and surgical technologists, are exposed to electrosurgical or laser smoke.[9] Although there has been no documented transmission of infectious disease as a result of surgical smoke, the potential for generating infectious viral fragments, particularly after treatment of venereal warts, may exist; however, currently there are no specific Occupational Health and Safety Administration (OSHA) standards for laser/electrosurgery plume hazards.[10]

Distribution of Smoke in the OR

All personnel working in the OR are familiar with the smell of surgical smoke that often fills the entire room; despite this pervasive smell at a distance from the operative site, it was commonly believed that only the scrubbed members of the surgical team were at greatest risk from inhaling the smoke and that personnel farther away were less at risk.[11] Early studies established that smoke plume had farther reaching effects than originally thought. One early study was conducted over a decade ago to determine the particle size and distribution of smoke in the OR.[12] The results of this study demonstrated that without smoke removal, particle concentration can increase from a baseline of about 60,000 particles per cubic foot to approximately one million particles per cubic foot within 5 minutes after activation of the electrosurgical unit (ESU). The concentration levels remain elevated throughout the duration of ESU use. Additionally, high concentrations were documented throughout the OR, thereby indicating that everyone present in the OR, not just the scrubbed team members, is exposed to similar particle concentrations. The authors went on to document that it took approximately 20 minutes for the OR ventilation system to return the room to baseline particle levels. A subsequent study also demonstrated how all members of the surgical team are potentially exposed to comparable levels of surgical smoke.[13] This study reported the speed of smoke particles ejected from animal tissue exposed to laser measured directly by laser Doppler velocimetry (LDV). Speeds recorded just above animal skin were in the range of 9 to 18 meters (29.52 to 59.05 feet) per second. However, when the particles were set in motion, the residual kinetic energy sent the particles up to about 0.87 meter (2.85 feet) from the skin surface.

Hazards Related to Laparoscopic Smoke Plume for Perioperative Personnel

As far back as 1996, the National Institute for Occupational Safety and Health (NIOSH) recognized the hazards of surgical smoke when it released a hazard control report outlining that at high concentrations, smoke generated by electrosurgical or laser systems caused ocular and upper respiratory tract irritation in health-care personnel and created visual problems for the surgeon; furthermore, the smoke has unpleasant odors and has been shown to have a mutagenic potential.[14]

Hydrocarbons, phenols, nitriles and fatty acids are the most prominent chemicals found in electrosurgery smoke, however, acrylonitrile and carbon monoxide are of greatest concern.[15] Acrylonitrile has toxic effects due to the formation of cyanide. Hydrogen cyanide is a colorless, toxic gas that may cause headache, weakness, throat irritation, vomiting, dyspnea, lacrimation, colic and nervousness after absorption through the skin and lungs. Long-term exposure causes 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. Benzene causes 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. The mutagenic effect created by thermal destruction of one gram of tissue is equivalent to that of three or six cigarettes for laser and electrocautery smoke, respectively. See Table 4 for a list of the potential health hazards associated with surgical smoke.

Table 4 - Health Hazards of Surgical Smoke[16]

Acute and chronic inflammatory respiratory changes (i.e., asthma, chronic bronchitis, emphysema)
Anemia
Anxiety
Carcinoma
Cardiovascular dysfunction
Colic
Dermatitis
Dizziness
Eye irritation
Headache
Hepatitis
Human Immunodeficiency Virus (HIV)
Hypoxia
Lacrimation
Leukemia
Lightheadedness
Nasopharyngeal lesions
Nausea or vomiting
Sneezing
Throat irritation
Weakness

Hazards Related to Smoke Plume for the Patient Undergoing Laparoscopic Surgery

While surgical smoke is encountered on a daily basis by all members of the surgical team, patients also are exposed, especially and uniquely so in laparoscopic and minimally invasive procedures where smoke is created and trapped in a closed and absorptive space.[17] Carbon monoxide (CO) is of particular concern in laparoscopic procedures because it is readily absorbed from the peritoneum into the bloodstream, thereby creating a route for systemic intoxication. The combination of CO and hemoglobin forms carboxyhemoglobin (COHb) and methemoglobin.[18] Excessive accumulations of either of these cause hypoxic stress in healthy individuals as a result of the reduced oxygen-carrying capacity of the blood. In patients with cardiovascular disease, this type of stress can further impair cardiovascular function. In general, patients will be protected from particulate air pollution by ventilation with their own supply of oxygen and/or anesthetic gases; nevertheless, they can be exposed to high levels of CO and hydrogen cyanide during laparoscopic procedures in which smoke is trapped and concentrated in the peritoneal cavity.[19]

In the early 1990s, a study was conducted to determine whether CO is produced by the use of electrosurgery during laparoscopic cholecystectomy, since the atmosphere of the peritoneal cavity is rendered hypoxic during laparoscopic cholecystectomy due to insufflation of 100% carbon dioxide (CO_2).[20] The results of this study demonstrated that CO was present in the peritoneal cavity five minutes after electrosurgery was initiated at an average concentration of 345 parts per million (ppm) and at the end of the procedure at a concentration of 475 ppm; these concentrations were well in excess of the 35 ppm upper limit for a one-hour exposure set by the Environmental Protection Agency (EPA). Furthermore, the carboxyhemoglobin concentrations were the same at the beginning of the case (mean 1.3%) and the end of the case (mean 1.2%), as well as the day after surgery (mean 1.1%). The authors concluded that while there was no evidence of significant absorption of CO in this group of patients, care should be taken to scavenge the gases produced by cautery of tissues to avoid contamination of the OR during laparoscopic surgery.

A subsequent study evaluated peritoneal absorption of the CO smoke component from tissue pyrolysis in patients undergoing laparoscopy in order to determine its effects and ability to be detected in peripheral blood.[21] Fifty patients had preoperative, intraoperative, and postoperative levels of carboxyhemoglobin (COHb) and pulse oximetry evaluated. The control group (25 patients) had no laser or cautery used and the study group (25 patients) had CO_2 laser used during the laparoscopic procedures. The results demonstrated that the control group showed no change in COHb, or intra-abdominal CO levels, before, during, and after the procedures, and no change in blood CO or pulse oximetry reading. The laser smoke group showed a statistically significant elevation in peripheral blood COHb levels, a significant increase in intra-abdominal CO concentration, and a lack of correlation of pulse oximetry and blood oxygen saturation experiments. The author concluded that CO is created in extremely large quantities during laser use at laparoscopy and is absorbed through the peritoneal cavity; patients are symptomatic of smoke poisoning with these elevations. Therefore, continuous or intermittent removal of smoke produced from laser use is recommended.

More recently, a report noted that laparoscopic peritoneal adhesion formation, which follows a pathway similar to laparotomy, is complicated and influenced by pressure, dry gas desiccation, and hypoxia caused and superimposed by the pneumoperitoneum.[22] It may further be affected by products of tissue combustion and inappropriate irrigation. The best measures to reduce adhesion formation outlined in this report are maintenance of a normal physiologic peritoneal state (i.e., wet and warm), gentle tissue handling, low intra-abdominal pressure, appropriate irrigation, and evacuation of smoke.

SOLUTIONS TO THE HAZARDS IDENTIFIED

In order to minimize exposure to laparoscopic surgical smoke and its associated health hazards for staff as well as patients, perioperative nurses must remain aware of effective strategies for use in all clinical practice settings where electrosurgery and other energy modalities are used. Effective risk reduction strategies should be implemented based upon the type of procedure and the anticipated amount of surgical smoke; they should include the use of appropriate equipment and evacuation methods.[23] The various solutions available today are described below.

OR Ventilation

Ventilation systems should maintain the air in the OR under positive pressure with a minimum of 15 exchanges per hour.[24]

Surgical Masks

Originally, the function of surgical masks was to protect the patient from infectious disease transmission from surgical team members; today, members of the surgical team must also be protected from aerosols released into the atmosphere from surgical smoke.[25] The filtration efficiency of surgical masks varies; however, in general, surgical masks filter particles to approximately 5 micrometers in size. Approximately 77% of the particulate matter in surgical smoke is 1.1 micrometers and smaller. High-filtration masks (see Figure 1), also known as laser masks, filter particles to about 0.1 micrometers in size and thus provide some respiratory protection; however viral particles can be much smaller than 0.1 micrometers. Therefore, personnel should wear high-filtration surgical masks during procedures that generate surgical smoke, as they may protect against residual plume in the air that has escaped capture via smoke evacuation.[26] However, these masks should *not* be viewed as absolute protection from chemical or particulate contaminants found in surgical smoke and should *not* be used as the first line of protection against surgical smoke inhalation.

Figure 1 – High Filtration Surgical Mask

Wall Suction

The simplest method of smoke evacuation in the OR is wall suction.[27] Because wall suction typically pulls less than 5 cubic feet per minute, it will be effective only on procedures that generate a small amount of smoke. When wall suction is used, an in-line filter also should be used; without the filter, OR personnel are not protected. Additionally, the suction lines and filters outside the OR must be kept clear in order for wall suction to be effective. In-line filters must be used and changed according to the manufacturer's written instructions; an overused filter provides no protection.

Portable Smoke Evacuation Systems

The most versatile options in many ORs are portable smoke evacuation systems (see Figure 2).[28] The most effective type of these systems is the triple-filter system equipped with an ultra-low particulate filter (ULPA) filter. ULPA filters are constructed with a depth media material capable of capturing 0.12 microns of particulate matter at an efficiency rate of 999.9999%; at this rate, only one in one million particles will escape capture. The triple-filter system includes a prefilter, which captures larger particles; the second stage of the filter is the ULPA filter, which captures the smaller particle components of smoke; and the final filter, which is composed of a special charcoal that captures the toxic chemicals found in surgical smoke. These types of filter systems generally have a variable suction volume capacity in order to accommodate various amounts of smoke production. In order to effectively capture surgical smoke, a portable smoke evacuation system should be able to pull 30 to 50 cubic feet per minute. A variety of capture devices are available for use with portable smoke evacuation systems, e.g., a small carriage unit that attaches to the ESU active electrode pencil and larger-sized tubing when use of the pencil-carriage device is not feasible. Used components of a smoke evacuation system, e.g., filters, tubing, and wands, should be disposed of as potentially infectious waste following standard precautions.[29]

Figure 2 – Portable Smoke Evacuation System

Centralized Smoke Evacuation System

A centralized smoke evacuation system is often installed in newly constructed ORs.[30] This type of system is quieter than portable systems because it is located outside of the OR; also it is usually more powerful than portable systems. A centralized smoke evacuation system provides smoke evacuation for several ORs at the same time and is convenient because it is always available; however, if it malfunctions, smoke evacuation is not available to multiple areas within the surgical suite.[31] The smoke evacuation line needs to be cleaned and flushed routinely, according to the manufacturer's recommendations, to ensure particulate matter buildup does not occur; smoke particulate can build up in the lumens of the centralized system, causing decreased suction capability and potential pathogen growth.[32]

Laparoscopic Smoke Evacuation

Surgical smoke should be removed with the use of a smoke evacuation system in both open and laparoscopic procedures.[33] As noted, accumulation of smoke during laparoscopic procedures can impede the surgeon's view; this can be somewhat minimized by using bipolar and ultrasonic instruments that generate a surgical plume that causes less deterioration of visibility during laparoscopic procedures.[34] Smoke from laparoscopic procedures also can be evacuated and filtered through a special laparoscopic smoke evacuation device that automatically provides a slow evacuation of smoke without destroying the pneumoperitoneum (see Figure 3).[35] In addition to improving the surgeon's visibility during the procedure, evacuating smoke reduces the amount of methemoglobin and carboxyhemoglobin in the patient's blood stream.[36]

Figure 3 – Laparoscopic Smoke Evacuation System

Surgical smoke also should be evacuated and filtered at the end of a laparoscopic procedure when the pneumoperitoneum is released.[37] The smoke generated in the pneumoperitoneum may be more concentrated than that generated in an open surgical procedure if it accumulates in the closed peritoneal cavity. While the risk to the patient due to this exposure of concentrated smoke has not yet been identified, there has been one report of suppressed cell-mediated intra-abdominal immunity during a laparoscopic procedure with pnuemoperitoneum. Port site metastasis, also known as the chimney effect, has been studied in an attempt to understand the capability of electrosurgical smoke serving as a vehicle for transplanting malignant cells to benign tissues. In addition, if at the end of the procedure, the smoke in the pneumoperitoneum is released directly from a cannula and without a filter, the concentrated smoke can expose members of the perioperative team to contaminants.

There are various filters, called "passive surgical smoke filters," that can be connected to trocars used during laparoscopic procedures to perform a number of functions.[38] While the term "passive" used in referring to this type of filter is derived from the need to differentiate this method of surgical smoke removal and treatment from "active" (i.e., vacuum-type) systems that are often used during open surgical procedures, a passive smoke filter is really anything but passive. The ideal profile of such a filter is as follows:

- Multiple filtration layers, specifically pre-filter, high efficiency filter, and an activated carbon filter:
    - The prefiltration layer should be designed to remove gross and fine particulate matter, viable cells, bacteria, and some viruses. The high efficiency filter should remove virtually all remaining viruses and other ultrafine particulate matter, while the activated carbon filter should remove all volatile chemical compounds and completely eliminate odor. As relates to overall performance, the smoke filter should retain greater than 99.999% of particles greater than 0.02 microns in diameter, leaving a smoke-free field of view.
- Verified bacteria and viral retention capability.
- A valve to allow release of gas without detectable odor (odor is an indicator of filter inefficiency).
- Adjustable gas flow from the peritoneum; maximum flow capacity should permit rapid gas exchange (12 Liters/minute at 15mm Hg).
- Provided sterile and appropriately packaged in a double-peel pouch for presentation to the surgical field.
- Ready-to-use; no assembly required.
- Easy to connect to the trocar with no leakage at the connection.
- Long lasting performance; it should be able to provide peak performance for procedures lasting up to four hours, even when continually challenged with elevated levels of moisture in overflow gas from the pneumoperitoneum.

The use of a passive smoke filter for laparoscopic procedures can result in both immediate cost savings as well as longer term cost avoidances.[39] Immediate cost savings are realized through shorter procedure times that may be directly correlated with the surgeon's unobstructed view of the operative field. When the ideal smoke filter is in place, there is no need for the surgeon to desufflate the pneumoperitoneum in order to clear the visual field. In addition, if the filter is equipped with a gas flow clamp, insufflation gas can be conserved by purging gas from the patient through the passive filter only when cauterization is actually being performed. The use of laparoscopic smoke filtration also results in cost avoidances. When a smoke filter is in use, surgeons do not have to continue working through an obstructed field; when operating in a clear field of view, fewer mistakes are made and consequently morbidity and mortality are reduced. Morbidity due to surgical errors leads to increased costs associated with treating the patient; both morbidity and mortality often lead to legal action against the physician and the health-care facility. As discussed previously, while patient safety regarding exposure to laparoscopic surgical smoke is an obvious concern, the safety of OR personnel also must be considered. Short-term respiratory illness due to surgical smoke exposure results in absenteeism, reduced productivity, and possibly scheduling problems; chronic staff illnesses often result in increased costs of care, while more severe cases can result in permanent disability and potential litigation.

Policies and Procedures

As noted earlier, the evacuation and filtration of surgical smoke is not currently mandated by any organization that has the force of law behind it, but it is recommended by various agencies and organizations, e.g., NIOSH and the Association of periOperative Registered Nurses (AORN).[40] Although many health-care professionals support the use of smoke evacuation systems in surgical services, others resist using these devices for various reasons, such as noise, distraction, and the ergonomic problems associated with equipment use.[41] Therefore, smoke evacuation policies and procedures for surgical and/or invasive procedure suites should be developed, implemented, and enforced. See Table 5 for a sample smoke evacuation policy.

Table 5 – Sample Smoke Evacuation Policy[42]

Department: Surgical Services / Operating Room
Title: Surgical Smoke Evacuation
Original Date:
Last Review Date:
Revision Dates:
Policy: It is the policy of (hospital or surgery center name) that surgical smoke generated during surgical cases will be captured and filtered through the use of smoke evacuators or in-line filters positioned on suction lines.

Procedure/Practice Guideline:

1. The reduction of surgical smoke shall be achieved through the use of smoke evacuation systems, in-line filters positioned on suction lines, or laparoscopic smoke evacuation devices.

2. During surgical procedures that generate small amounts of plume:
    a. An in-line filter (0.1-micron filtration capabilities) shall be positioned between the wall suction and the suction canister so that fluids are not transferred through the filter media.
    b. In-line filters will be changed according to the manufacturer's recommendations.
    c. A suction tubing no longer than 12 feet in length will be used with a suction tip or attached directly to the ESU pencil.
    d. Wall suction devices have low suction power that can limit the efficiency of surgical smoke evacuation but are suitable for minimal plume evacuation.
    e. Contaminated in-line filters and suction tubings will be disposed of by personnel using personal protective equipment.

3. During surgical procedures that generate large amounts of plume:
    a. A smoke evacuator will be used.
    b. Corrugated smoke evacuation tubing with a smooth inner lumen will be connected directly to the smoke evacuator.
    c. The standard suction tubing will be used to evacuate fluid and the corrugated tubing will be used to evacuate surgical smoke.
    d. The plume capture device will be positioned in close proximity (i.e., within two inches) of the site where the surgical smoke is being generated.
    e. The smoke evacuation filter will be changed as recommended by the manufacturer.
    f. Devices, if available, will be attached to the smoke evacuator that will automatically start and stop the smoke evacuator as surgical smoke is being generated.

4. Laparoscopic surgery should be performed in a manner that minimizes the surgical team's exposure to blood, fluids, droplets, noxious fumes, gases, or surgical smoke. The release of gas, ESU smoke, ultrasonic plume, and laser smoke during endoscopic surgery exposes the surgical team to the hazards of surgical smoke.
    a. Surgical smoke should be evacuated throughout the laparoscopic procedure by using a laparoscopic smoke evacuation device and by following the manufacturer's recommendations.
    b. The smoke evacuation device should have a 0.1-micron filtration capability.
    c. A closed system should be used when releasing insufflated gases. The release of the pnuemoperitoneum should be performed using a closed system that may involve a 0.1 in-line filter on the suction line, a smoke evacuation system that employs an irrigation/suction probe, or a smoke evacuator equipped to manually release insufflated gases.

5. Air exchanges in the OR should adhere to guidelines established by the Centers for Disease Control and Prevention and the American Institute Architects (AIA). All air should be treated with appropriate filters as recommended by the AIA.

Definition of Surgical Smoke: Surgical smoke and aerosolization are created as a result of the destruction of tissue by electrosurgical units (ESUs), lasers, radio frequency devices, ultrasonic devices, power tools, and other surgical tools. Research studies have confirmed that surgical smoke (i.e., plume) can contain toxic gases and vapors such as benzene, hydrogen cyanide, and formaldehyde along with bioaerosols, dead and live cellular material (including blood fragments), and viruses. At high concentrations, surgical smoke causes ocular and upper respiratory tract irritation in health-care workers, and creates obstructive visual problems for the surgeon. Surgical smoke has unpleasant odors and has been shown to have mutagenic potential.

As with all operating policies and procedures, compliance with smoke evacuation policies and guidelines is a key component in providing a safe environment of care for both patients and perioperative staff members. A recent descriptive explanatory/exploratory study demonstrated that perioperative nurses' compliance with smoke evacuation recommendations is not consistent.[43] In this study, key indicators for compliance with electrosurgical smoke evacuation recommendations based on nurses' individual innovativeness characteristics, perceptions of the attributes of smoke evacuation recommendations, and organizational innovativeness characteristics were investigated. The findings of the study provide implications for improving nurses' compliance with smoke evacuation recommendations. Individual innovativeness characteristics, including nurses' knowledge and training, were most strongly linked to compliance with smoke evacuation guidelines. The key indicators that promote surgical smoke evacuation can provide direction to guide the content of educational activities and help identify the personnel and settings that are most in need of this information. The barriers to compliance were lack of equipment, physician resistance, noise, and staff member complacency. Strategies identified to improve compliance included vendor demonstrations on the ease of smoke evacuation device use, which can show nurses that smoke evacuation is compatible with nursing practice; in addition, facility leaders should provide smoke evacuation policies that are easy to understand and should also enforce these policies.

SELECTION CRITERIA FOR SMOKE EVACUATION SYSTEMS FOR LAPAROSCOPIC PROCEDURES

As with all products used in the OR, patient safety should be the primary concern of perioperative nurses when evaluating and selecting new products or medical devices.[44] Patient safety, i.e., freedom from acquired injury, is one of the four domains of perioperative nursing as specified in the Perioperative Nursing Data Set (PNDS).[45] In the selection of laparoscopic smoke evacuation systems, OR personnel safety also should be considered. General criteria for evaluation of laparoscopic smoke evacuation systems include, but are not limited to:[46]

- Safety, performance, quality, and improved efficiency;
- Ease of use;
- Compatibility with other products or medical devices;

- Impact on quality patient care and clinical outcomes;
- Efficacy;
- Cost/value analysis;
- New technology competitiveness;
- Adaptability to future technology;
- Availability and quality of service after the purchase; and
- Investment in personnel training.

Specifically, during the selection process for laparoscopic smoke evacuation systems, members of the perioperative team should evaluate available technology and then select a smoke evacuation system that fulfills the comprehensive needs of the facility; in addition to the general criteria noted above, other points to consider include:[47]

- Filter and canister design; availability of replacement filters;
- Filter monitoring;
- Fluid removal capabilities;
- Foot pedal activation versus automatic activation;
- Noise production;
- Single use versus reusable; and
- Size.

As discussed above, a laparoscopic smoke evacuation system should be equipped with a passive disposable multi-stage filter system that captures airborne particulate matter, vapor and odor with a 99.999% efficiency level (i.e., the ULPA filter traps smoke, particulates and aerosolized pathogens); the activated charcoal membrane absorbs odors and chemical toxins. Flow rates can be pre-set to optimize smoke removal without losing pneumoperitoneum.

In order to address the factors associated with resistance to the use of laparoscopic smoke evacuation systems identified above, other desirable characteristics include:

- Efficient capture of smoke–high air flow with variable speed control maintains a clear field of vision.
- Ease of use–setup should be easy and require minimal involvement once the system has been set up.
- Quiet–the elevated intraperitoneal pressure pushes out the smoke, etc. along with the CO_2; because no vacuum pump is required, it functions silently.
- Easy connection–no extra tubing required.
- Low maintenance or maintenance-free.

SUMMARY

Laparoscopic surgery is one of the most significant advances in the practice of surgery, reflected by its ongoing acceptance and technological advancements. While there are many advantages associated with laparoscopic surgery, one associated health hazard is exposure to surgical smoke resulting from the use of electrosurgery. Furthermore, in today's surgical practice settings, smoke is increasingly present due to the rising use of other energy modalities, such as the laser and harmonic scalpel. At a minimum, surgical smoke is a toxin similar to cigarette smoke; at worst, other dangers exist, as it is well-documented that this smoke contains potentially harmful, mutagenic biological materials, gases, and particulates. It has long been recognized that members of the surgical team have been exposed to the hazards of surgical smoke on a daily basis for many years, but today, the hazards to the patient are also a cause for concern. Patients are exposed to surgical smoke, particularly and uniquely so in laparoscopic and minimally invasive surgical procedures, where smoke is created and trapped in a closed and absorptive space. The associated hazards of surgical smoke include the potential transmission of infectious or chemical agents into the lungs, bloodstream, or skin of patients and health-care team members.

While evacuation of surgical smoke is not currently mandated by any organization that has the force of law behind it, it is recommended by various agencies and organizations. Furthermore, many health-care professionals support the use of smoke evacuation systems in surgical services, while others resist using these devices for a variety of reasons. Effective solutions should be implemented based upon the type of procedure and the anticipated amount of surgical smoke; they should include the use of appropriate equipment and evacuation methods. Moreover, the capture as well as the release of surgical smoke should be performed in a safe manner that does not cause harm to the patient or members of the surgical team. Solutions to reduce the risk of exposure for patients and all members of the surgical team include evacuating and filtering surgical smoke during a laparoscopic procedure and at the end of the procedure when the pneumoperitoneum is released, with the use of a smoke evacuation system specifically intended for this application. The smoke generated in the pneumoperitoneum may be more concentrated than that generated in an open surgical procedure if it accumulates in the closed cavity; if at the end of the procedure, the smoke in the pneumoperitoneum is released directly from a cannula and without a filter, the concentrated smoke can expose members of the perioperative team to contaminants.

As a safety advocate, the perioperative nurse must remain knowledgeable about the risks and hazards of exposure to laparoscopic surgical smoke in the clinical practice setting, as well as the various solutions available today, in order to provide a safe environment of care for surgeons, staff, and patients.

GLOSSARY

Activated Carbon	A carbon-based compound baked at high temperatures without the presence of oxygen, a process that removes organic compound and leaves only a carbon matrix behind. Through this process, the carbon granules become full of active sites where organic molecules may be captured without changing the carbon structure.
Aerosol	A liquid or solution dispersed in air in the form of a fine mist.
Airborne Contaminant	A substance carried by or through the air that may contaminate (infect, pollute, defile) another substance.
Bioaerosol	An aerosol containing biologically active bacteria, spores, viruses, toxins, and other similar material.
Bloodborne Pathogen	A pathogenic microorganism present in human blood that can cause disease in humans. Pathogenic microorganisms include, but are not limited to, HBV and HIV.
Charcoal Filter	A filter for odor and gas adsorption. It may or may not be combined with a depth media filter for capture of gross particulates. Odor-control efficiency is related to the filter's CTC (carbon tetrachloride) rating. The CTC rating is the percent by weight of CTC vapor the charcoal can adsorb. One pound of CTC-60 charcoal can adsorb up to 60% of its weight or 0.6 pounds of CTC vapor.
Depth Media Filter	A filter consisting of randomly oriented glass or polypropylene fibers. The open spaces between the densely packed fibers are much larger than the particles to be captured, so filtering action depends on the particles coming in contact with and adhering to the fibers, through the forces of inertial impaction, electrostatic attraction, and diffusion.

Electrosurgery	The cutting and coagulation of body tissue with a high-frequency (i.e., radio frequency) current.
Mutagen	A substance that causes the occurrence of a sudden variation in some inheritable characteristic in a germ cell of an individual animal or plant.
Particulate	A formed element or discrete body within a surrounding liquid or semiliquid material.
Personal Protective Equipment (PPE)	Protective equipment (e.g., masks, gloves, fluid-resistant gowns, goggles, and face shields) for eyes, face, head, and extremities; protective clothing; respiratory devices; and protective shields and barriers designed to protect the wearer from injury.
Pneumoperitoneum	The presence of air within the peritoneal cavity of the abdomen often induced for diagnostic purposes.
Prefilter	A filter made of sponge or wire grating that is used to capture objects, fluid, or gross particulates that are accidentally sucked into the airstream of a smoke evacuator and may subsequently damage the high-efficiency filter or the vacuum pump.
Pyrolysis	Decomposition or transformation of a chemical compound caused by heat.
Surgical Smoke	Smoke that is generated when tissue is heated and cellular fluid is vaporized by the thermal action of an energy source.
Ultra Low Particulate Air (ULPA) Filter	Theoretically, an UPLA filter can remove from the air 99.9999% of bacteria, dust, pollen, mold, and particles with a size of 120 nanometers or larger.
Ultrasonic Scalpel	A cutting/coagulation device that converts electrical energy into mechanical energy, providing a rapid ultrasonic motion.

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