GUIDELINE FOR SURGICAL SMOKE SAFETY

The Guideline for Surgical Smoke Safety has been approved by the AORN Guidelines Advisory Board. It was presented as a proposed guideline for comments by members and others. The guideline is effective December 15, 2016. The recommendations in the guideline are intended to be achievable and represent what is believed to be an optimal level of practice. Policies and procedures will reflect variations in practice settings and/or clinical situations that determine the degree to which the guideline can be implemented. AORN recognizes the many diverse settings in which perioperative nurses practice; therefore, this guideline is adaptable to all areas where operative or other invasive procedures may be performed.

Purpose

This document provides guidance on surgical smoke safety precautions to help the perioperative team establish a safe environment for the surgical patient and team members through consistent use of control measures.

Surgical smoke is the by-product of use of energy-generating devices (eg, electrosurgery units, lasers, powered instruments).[1] When surgical energy devices raise intracellular temperatures to 100° C (212° F) or higher, the tissue vaporizes, producing surgical smoke.[2] This gaseous by-product is visible and malodorous.[3] Surgical smoke may contain gaseous toxic compounds (eg, hydrogen cyanide, toluene, benzene), bio-aerosols, viruses (eg, human papilloma virus [HPV], human immunodeficiency virus [HIV]),[3] viable cancer cells, non-viable particles (ie, lung damaging dust of 0.5 µm to 5.0 µm), carbonized tissue,[3] blood fragments, and bacteria. The water vapor content of surgical smoke ranges from 1% to 11%[4] and serves as a carrier for the compounds, viruses, and other substances. Researchers began analyzing the contents of surgical smoke in the early 1980s. In a 1981 study, Tomita et al[5] found that the contents of surgical smoke are similar to the contents of cigarettes, with known and suspected carcinogens and mutagens.

Electrosurgical devices use radio-frequency current to cut and coagulate. Heat is generated in the body tissue through which the current passes. The heat causes cell walls to explode, releasing the cellular fluid as steam and the cell contents into the air, forming surgical smoke. Lasers produce an intense, coherent, directional beam of light and also produce high heat, which raises the temperature within the cell, vaporizing the contents and releasing steam and cell contents.[1] Ultrasonic devices remove tissue by rapid mechanical action. Ultrasonic aspirators produce a fine mist, and ultrasonic scalpels produce a vapor.[1] High-speed electrical devices (eg, bone saws, drills) cut, dissect, and resect tissue. The mechanical action of the saw or drill combined with irrigation fluid used to cool the device produces aerosols that may contain viable bloodborne pathogens.[1]

The Occupational Safety and Health Administration (OSHA) has estimated that more than 500,000 health care workers are exposed to surgical smoke every year.[6] Perioperative nurses report twice the incidence of many respiratory problems compared to the general population.[7,8] Case reports have established the link between inhalation of surgical smoke during excision of anogenital condylomata procedures to transmission of HPV to health care providers.[9-11] For example, a laser surgeon developed laryngeal papillomatosis of the same virus type as his patient,[10] and experts at a virological institute confirmed a high probability of occupational exposure in a gynecologic perioperative nurse who developed recurrent and histologically proven laryngeal papillomatosis.[9]

Surgical smoke exposure is also hazardous to patients. Risks to patients include loss of visibility in the surgical field during minimally invasive procedures[12-18] with potential to delay the procedure,[19-22] port site metastasis,[23] exposure to carbon monoxide,[22,24,25] and increased levels of carboxyhemoglobin.[22,24]

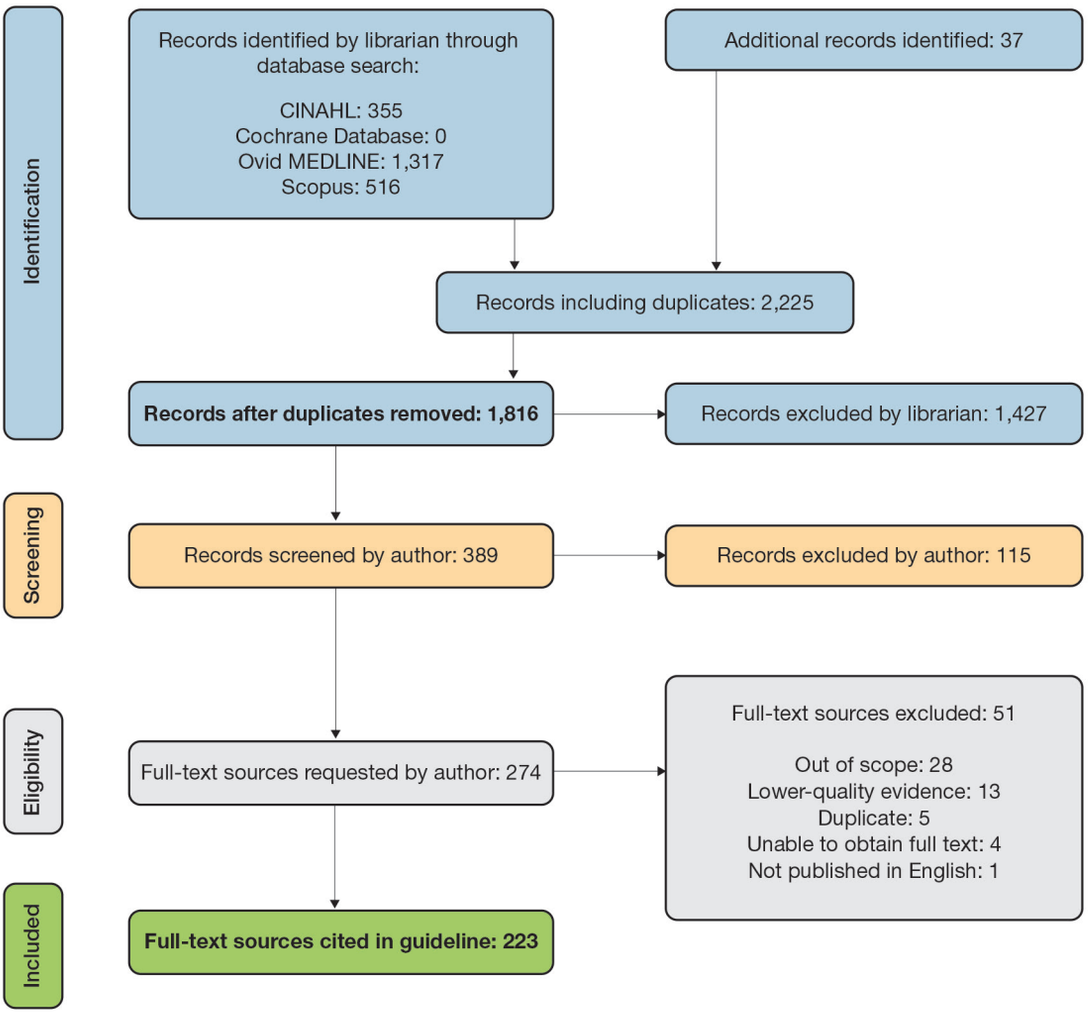
AORN, the National Institute for Occupational Safety and Health (NIOSH),[26] and other professional organizations[27-31] have recommended surgical smoke evacuation for more than 20 years. Perioperative team members continue to demonstrate a lack of knowledge of the hazards of surgical smoke[32-34] and a lack of compliance in evacuating surgical smoke.[8,32,33,35] Even though smoke generated by electrosurgery[5] is more hazardous than laser-generated surgical smoke, there is greater compliance with smoke evacuation for laser procedures.[36,37]

Surgical smoke is often referred to as *surgical plume, smoke plume, bio-aerosols, laser-generated airborne contaminants,* and *lung-damaging dust.* For the purpose of this document, the term *surgical smoke* will be used unless another term has been specifically used in a reference source.

Evidence Review

A medical librarian conducted systematic searches of the databases MEDLINE®, CINAHL®, Scopus®, and the Cochrane Database of Systematic Reviews. Results were limited to literature published in English from January 1985 to November 2015. During the development of the guideline, the lead author requested additional articles that either did not fit the original search criteria or were discovered during the evidence appraisal process, and the lead author and the medical librarian identified relevant guidelines

FIGURE 1. FLOW DIAGRAM OF LITERATURE SEARCH RESULTS



Adapted from Moher D, Liberati A, Tetzlaff J, Atman DG; The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA Statement. PLoS Med. *2009;6(6):e1000097.*

from government agencies and standards-setting bodies. Updated searches were completed in January 2016.

Search terms related to procedures included the subject headings and keywords *diathermy, cautery, laser, electrosurgery,* and *surgical procedures, operative.* Search terms and keywords related to by-products included *smoke, plume, fume, exhaust, mist, particulate matter, bioaerosols, aerosols, smoke evacuation, smoke extractor,* and *occupational air pollutants.*

Inclusion criteria were research and non-research literature in English, complete publications, and publication dates within the time restriction unless none were available. Excluded were non-peer-reviewed publications and literature on surgical smoke safety. Letters and editorials were excluded. Low-quality evidence was excluded when higher-quality evidence was available, and literature outside the time restriction was excluded when literature within the time restriction was available (Figure 1).

Articles identified in the search were provided to the project team for evaluation. The team consisted of the lead author and two evidence appraisers. The lead author divided the search results into topics and assigned members of the team to review and critically appraise each article using the AORN Research or Non-Research Evidence Appraisal Tools as appropriate. The literature was independently evaluated and appraised according to the strength and quality of the evidence. Each article was then assigned an appraisal score. The appraisal score is noted in brackets after each reference, as applicable.

The collective evidence supporting each intervention within a specific recommendation was summarized, and the AORN Evidence Rating Model was used to rate the strength of the evidence. Factors considered in the review of the collective evidence were the quality of the evidence, the quantity of similar evidence on a given topic, and the consistency of evidence

supporting a recommendation. The evidence rating is noted in brackets after each intervention.

Note: *The evidence summary table is available at http://www.aorn.org/evidencetables/.*

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Recommendation I

The health care organization should provide a surgical smoke-free work environment.

Under the General Duty Clause, Section 5(a)(1) of the Occupational Safety and Health Act of 1970, employers are required to provide their employees with a place of employment that is "free from recognizable hazards that are causing or likely to cause death or serious harm to employees."[38,39]

A court interpretation of the Occupational Safety and Health Administration (OSHA) General Duty Clause is that the employer has a legal obligation to provide a workplace free of conditions or activities that either the employer or industry recognizes as hazardous and that cause or are likely to cause death or serious physical harm to employees when there is a feasible method to abate the hazard.[40]

I.a. The health care organization should assess the perioperative team's risk of exposure to surgical smoke. *[2: High Evidence]*

The collective evidence describes the contents of surgical smoke and demonstrates the exposure risks and hazards to the perioperative team. Surgical smoke contains many components that are recognized health hazards. The identified contents of surgical smoke include

- aromatic hydrocarbons[41] (eg, benzene,[41-52] toluene,[41,43,45-49,50-58] xylene[41,46,51,52,57,58]),
- volatile organic compounds,[59-61]
- polycyclic aromatic hydrocarbons[41,62,63] (eg, benzo[a]pyrene, dibenzo[a,h]anthracene, anthracene[64]),
- hydrogen cyanide,[41,49,61,64]
- inorganic gases[60] (eg, carbon monoxide[19,20,46,49,65]),
- nitriles[66] (eg, acetonitrile, acrylonitrile[43,46,47]),
- aldehydes[52,60] (eg, acetaldehyde,[53,54,56,60] formaldehyde[41,46,49,53,54,56,64]),
- particles,[19,67-79]
- viruses[3,80-87] (eg, HPV,[88-95] HIV[96,97]),
- bacteria,[87,98-104]
- blood,[100,105-110] and
- cancer cells.[23,111-113]

Chemicals

The collective evidence establishes the presence of harmful chemicals in surgical smoke, with an estimated 150 chemical compounds[114,115] discovered using gas chromatography,[50,57,63] a combination of gas chromatography and mass spectrometry,[45-47,51,52,55,58-62,116-118] and laser spectroscopy[43,44,48,119-121] (Table 1). The content of surgical smoke varies by the type of tissue treated (eg, muscle, fat),[19,44,47,48,55,57,60,61,122,123] type of energy-generating device (eg, laser,[49] electrosurgical unit [ESU]) used,[19,60,118,123] duration of the procedure,[55] and the amount of time the energy-generating device was activated.[19,43,48,57]

Näslund Andréasson et al[63] collected personal and stationary samplings of polycyclic aromatic hydrocarbons (PAHs) in electrocautery smoke during 40 peritonectomy procedures for *pseudomyxoma peritonei* (n = 22), colorectal cancer (n = 11), appendiceal cancer (n = 5), and ovarian cancer (n = 2). The primary aim of the study was to identify and quantify the US Environmental Protection Agency's 16 priority pollutant PAHs (Table 2). All 16 PAHs were detected in personal and stationary samples. Personal samplings were collected using a 40-mm absorbent filter cassette fixed near the surgeon's breathing zone to absorb organic compounds. The stationary samplings were collected with a 20-mm smoke evacuator hose connected to a smoke evacuator system. The absorbent filter cassette tubing was inserted in a small slit 5 cm from the tip of the electrocautery device.

Naphthalene, a possible human carcinogen, was the most abundant PAH and was found in all but one of the samples (97.5%). In addition to naphthalene, phenanthrene (93%), florene (63.3%), acenaphthene (40%), and acenaphthylene (36.7%) were detected in the personal samplings. Acenaphthylene (93.3%), phenanthrene (90%), acenaphthene (90%), and florene (83.3%) were detected in the stationary samplings. The researchers postulated that long-term exposure to PAHs could lead to high cumulative levels of PAHs in perioperative team members, and consideration should be given to the possibility that simultaneous exposure to particles, PAHs, and volatile organic compounds may have synergistic and additive effects. More studies are needed to evaluate the possible risk of PAH exposure in the OR.[63]

Petrus et al[44] used laser photoacoustic spectroscopy to quantitatively analyze the trace gas concentrations in surgical smoke produced in vitro in nitrogen or synthetic air atmospheres. The researchers used a carbon dioxide (CO_2) laser to generate surgical smoke by irradiating fresh animal tissue, then measured the levels of ethylene, benzene, ammonia, and methanol. Benzene was detected in high concentrations in all smoke samples at a level hundreds of time higher than the recommended exposure limit established by OSHA and NIOSH. Ammonia also exceeded the exposure limit. Methanol and

TABLE 1. CHEMICAL CONTENTS OF SURGICAL SMOKE[1]

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

REFERENCE

1. *Barrett WL, Garber SM. Surgical smoke: a review of the literature.* Business Briefing: Global Surgery. *2004:1-7.*

From Ulmer BC. The hazards of surgical smoke. AORN J. *2008;87(4):721-734. Reprinted with permission.*

ethylene were detected in the smoke but were within recommended exposure limits. The researchers concluded that additional factors to consider are the cumulative effect of all volatile organic compounds released during laser surgery and the harmful effects to the surgical team of continuous exposure by surgical smoke inhalation.

In a subsequent study, Petrus et al[43] used the laser photoacoustic spectroscopy technique to quantitatively analyze the concentrations of acetonitrile, acrolein, ammonia, benzene, and toluene in surgical smoke in vitro. A CO_2 laser was used to irradiate fresh animal tissue to generate surgical smoke. The researchers found that all of the gases were present in the surgical smoke, with an average gas concentration of acetonitrile 190 ppm, acrolein 35 ppm, ammonia 25 ppm, benzene 20 ppm, ethylene 0.410 ppm, and toluene 45 ppm.

Particles

The collective evidence indicates that the particles in surgical smoke generated by surgical energy-generating devices (eg, monopolar and bipolar electrosurgery, lasers) are within the respirable range.[67-75,77] Electrosurgery generates the smallest aerodynamic size particles (< 0.07 µm to 0.1 µm); laser tissue ablation creates larger particles (~ 0.31 µm); and ultrasonic scalpels create the largest particles (0.35 µm to 6.5 µm).[19]

Ragde et al[77] conducted a study to assess the exposure of surgical personnel to ultrafine particles (UFPs), to identify the predictors of exposure, and to characterize the particle size distribution of surgical smoke. The researchers measured personal exposures for the surgeon, assistant, scrub nurse, and anesthetic nurse during five different procedures (ie, nephrectomy, breast reduction, abdominoplasty, hip replacement, transurethral resection of the prostate) using spectrometry to assess the exposure to UFPs and characterize the particle distribution. Possible predictors of exposure were investigated using linear mixed effects models.

Exposure to UFPs was highest during abdominoplasty and lowest during hip replacement surgeries. Seventy percent or more of the measured particles were in the ultrafine range. The use of electrosurgery resulted in short-term, high-peak exposure with a maximum peak exposure of 272,000 particles cm^{-3} during a breast reduction surgery. The peaks corresponded to the use of the electrosurgery unit. Nephrectomy, transurethral resection of the prostate, and hip replacement surgeries produced the smallest size particles (9 nm) and also had the highest percentages of UFPs. Breast reduction surgery and abdominoplasty produced larger sized particles (70 nm and 81 nm, respectively) and had a lower percentage of

TABLE 2. US ENVIRONMENTAL PROTECTION AGENCY PRIORITY POLLUTANTS POLYCYCLIC AROMATIC HYDROCARBONS[1]

- Benzo[a]anthracene
- Benzo[a]pyrene
- Benzo[b]fluoranthene
- Benzo[k]fluoranthene
- Chrysene/triphenylene
- Dibenzo[a,h]anthracene
- Indenol[1,2,3-cd]pyrene
- Acenaphthene
- Acenaphthylene
- Anthracene
- Benzo[ghi]perylene
- Phenanthrene
- Fluoranthene
- Fluorene
- Naphthalene
- Pyrene

REFERENCE

1. *Näslund Andréasson S, Mahteme H, Sahlberg B, Anundi H. Polycyclic aromatic hydrocarbons in electrocautery smoke during peritonectomy procedures.* J Environ Public Health. *2012;2012:929053.*

UFPs. There were no significant differences in exposure among the team members. The researchers concluded that the use of electrosurgery resulted in short-term, high-peak exposures to UFPs and recommended the correct use of smoke evacuators, the use of a built-in smoke evacuator tubing on the electrosurgery pencil, and the use of two smoke evacuators if two electrosurgery pencils are required.[77]

Wang et al[73] conducted a prospective study to analyze fine particles < 2.5 µm ($PM_{2.5}$) in surgical smoke by time and distance during urology procedures. The three types of surgeries included in the study were open surgeries, laparoscopic partial nephrectomy, and transurethral resection of bladder tumor. Three subtypes of the open surgery group, according to surgery depth, were inguinal lymph node dissection for penile cancer (superficial), partial nephrectomy (abdominal), and radical prostatectomy (pelvic). The sample size of each group was five patients per surgery. All procedures were performed in the same laminar airflow room. An instrument using a laser light scattering technique measured the number of particles. Particle counts were expressed as a concentration per 0.01 $feet^3$. The instrument calculated an adjusted measurement of $PM_{2.5}$ mass (µg/m^3). Particle counts were measured at 40 cm, 60 cm, and 120 cm during open and laparoscopic surgeries to simulate the positions of the surgeon, assistant, and scrub person and were measured at 40 cm during the transurethral surgeries.

During the open surgeries, $PM_{2.5}$ was measured with and without wall suction for smoke evacuation. To evaluate the air quality, the researchers used the AIR Quality Index (AQI), the National Ambient Air Quality Standards for Particle Pollution revised by the US Environmental Protection Agency. Background particle measurements in the OR before the surgeries were nearly 5 µg/m^3. The AQI of the air 40 cm from the open surgery incisions turned to unhealthy and very unhealthy in 3 to 6 seconds. In laparoscopic surgeries, the AQI 40 cm from the trocar reached hazardous levels in 3 seconds after the trocar valve was opened, releasing the surgical smoke. In the transurethral surgeries, the AQI was moderate 40 cm from the resectoscope. Use of wall suction decreased the inhalation dose of fine particles 48% in superficial surgeries and 52% in abdominal surgeries. The main finding of this study was that the concentration of fine particles of a single smoke plume could become very unhealthy for the surgeon. The researchers concluded that increasing the distance to the incision site decreased the concentration and inhalation of fine particles, and the use of smoke evacuation can reduce the concentration of fine particles.[73]

HPV

The evidence regarding the presence of HPV in surgical smoke is inconclusive. Human papillomavirus has been detected in the surgical smoke generated by lasers and ESUs during treatment of genital infections,[88-91,124] verrucae,[93,94] laryngeal papillomavirus,[92] and bovine papillomavirus-induced cutaneous fibropapillomas.[81] However, some studies have found no detectable HPV in laser plume generated during treatment of laryngeal papillomas.[125-127]

Kashima et al[92] conducted a prospective study to determine whether HPV DNA was in the smoke plume after CO_2 laser treatment of recurrent respiratory papillomatosis (RRP). Twenty-two patients with diagnoses of adult-onset RRP (n = 7), juvenile-onset RRP (n = 12), laryngeal carcinoma (n = 2), and nonspecific laryngitis (n = 1) participated in the study. The researchers collected 30 paired tissue and smoke samples during microlaryngoscopy with CO_2 laser excision under general anesthesia. To avoid contamination, the samples were processed separately with a polymerase chain reaction (PCR) assay for amplification of HPV-6 and HPV-11 sequences. Seventeen of the 30 smoke samples were positive for HPV DNA; three of the samples were identified as HPV-6 and 14 samples as HPV-11. Only the RRP specimens

were HPV positive. The DNA types HPV-6 and HPV-11 are recognized as etiological agents in RRP. The researchers concluded that the consequences of HPV in smoke plume are unknown. To reduce the risk of potential infection to the patient and perioperative team members, they recommended using personal protective equipment (PPE) (eg, masks, gowns, gloves) and a gas-scavenging system whenever viral-infected lesions are treated with a CO_2 laser.

In a prospective study, Hughes and Hughes[126] collected and evaluated the laser plume of erbium:YAG laser-treated human warts to determine the presence or absence of HPV DNA in the plume. The researchers excised half of five patients' *verrucae vulgaris* and submitted the specimens for histopathological diagnosis and HPV DNA detection (HPV-1 and HPV-2) with in situ hybridization for HPV. The remaining half of the *verrucae vulgaris* were ablated with the erbium:YAG laser. A smoke evacuator collected the plume for evaluation of HPV DNA by PCR with consensus primers for the HPV previously detected in the *verruca vulgaris* specimens. The histopathological diagnosis of all five specimens was *verruca vulgaris*. All of the specimens with in situ hybridization contained HPV-2 DNA. Using PCR with consensus primers for HPV-2, the researchers did not detect HPV-2 in the laser plume of the same specimens. They concluded that the negative HPV plume results with the erbium:YAG laser were contradictory to the positive HPV plume findings in two other studies[93,94] in which CO_2 laser and electrosurgical excision and CO_2 laser excision were used. Hughes and Hughes postulated that the negative results could be a result of the radical explosive ejection of the erbium:YAG laser disrupting the HPV and rendering it undetectable.

Studies by Bergbrant et al,[124] Sood et al,[88] and Sawchuck et al[93] describe the risks of HPV exposure from ESU-generated smoke.

HIV

Johnson and Robinson[97] conducted a study to determine whether infectious HIV-1 could be isolated from aerosols generated from human blood containing HIV-1 during orthopedic and other surgical procedures that generate aerosols. The researchers prepared a mixture of human packed red blood cells negative for cytomegalovirus and HIV antibodies, a culture medium, and a culture medium containing a 10^5 tissue culture infectious dose of HIV-1. Individually, samples of the mixture were subjected to electrocautery in the coagulation and cutting modes, a high-speed bone cutting router, an oscillating bone saw, and a wound irrigation syringe jet. The cool aerosol or smoke plume generated by the procedures was suctioned and cultured.

Cultures positive for HIV-1 developed from the cool aerosols generated by the effects of the high-speed router tip and the oscillating bone saw on the blood mixture containing HIV-1. Cultures negative for HIV-1 developed from the cool aerosols generated by the wound irrigation syringe jet. Negative culture results were also obtained from six experiments of cutting and six experiments of coagulation with the electrocautery. The researchers concluded that infectious HIV-1 could be isolated from cool aerosols created from HIV-1 positive blood exposed to orthopedic routers and oscillating saws but that the high temperature of the electrocautery may inactivate HIV-1.[97]

Blood

Jewett et al[107] conducted a study to characterize the hemoglobin content by particle size of blood-containing aerosols generated by surgical power tools. Part of this study extends the work of Johnson and Robinson[97] described earlier. The researchers used two different protocols to generate aerosols. In a laboratory simulation of an operating room (OR), an oscillating bone saw, a high-speed air-driven drill, and a high-speed irrigating drill were used to "operate" on bone, and an ESU was used to cut and coagulate tendons. To simulate the blood present during surgery, blood was dripped onto the working area. The researchers collected a sampling from each test condition in addition to a control sampling using distilled water instead of blood. The second protocol was the same as that described by Johnson and Robinson[97] except the blood was not infected with HIV.

All of the instrumentation tested produced blood-containing aerosol particles in the respirable size range (< 5 µm). The researchers concluded that hemoglobin is an adequate marker of blood and therefore of bloodborne pathogens. The results suggest there is potential for breathing-zone exposure to respirable blood-containing particles during surgery performed with similar instrumentation. Additional research is needed in clinical settings.[107]

In a prospective, single-center trial, Ishihama et al[106] investigated whether blood-contaminated aerosols were present in a room where oral surgery procedures (N = 100) were performed with a high-speed drill. The sampling results were 76% positive in blood presumptive tests at 20 cm (7.9 inches) from the surgical site and 57% positive at 100 cm (39.4 inches) from the surgical site. The researchers concluded that these results suggest a risk for floating blood particles with the potential to cause airborne infection during use of high-speed instruments in oral surgery procedures.

In a subsequent study, Ishihama et al[105] used two protocols to investigate the presence of blood-contaminated aerosols in ORs during oral

surgery procedures. For both protocols, the exhaust ducts of the central air-conditioning system were covered with a filter to collect the atmospheric samples. In the accumulation protocol, the researchers left the filters in place for 1, 2, and 4 weeks in one OR. In the second protocol, to analyze contributing factors, the test filters were changed after each surgical procedure. A leucomalachite green presumptive test for blood was used to test each filter. The researchers also collected additional data (ie, the type of procedure, the use of a high-speed rotating instrument or electric coagulator device, blood loss volume, and length of the procedure).

In the accumulation protocol, the positive sites for blood increased from 26 after 1 week to 92 and 143 after 2 and 4 weeks, respectively. Following the individual procedures, there were positive sites for blood in 21 of 33 procedures. Contributing factors to a positive result for blood included use of a high-speed instrument (9 of 10 surgeries), use of an electric coagulator (16 of 17 surgeries), and use of a high-speed instrument or electric coagulator (20 of 21 surgeries). Contributing factors to a negative result for blood included use of no device (11 of 12 surgeries). The researchers discussed the lack of evidence of infection risk from inhalation of floating infectious materials. Most health care workers who contract an occupational infection cannot pinpoint a causative injury such as a mucous membrane exposure. The researchers recommended using caution, especially for personnel who remain in the OR for long periods of time (eg, anesthesia providers, surgical assistants).[105]

I.a.1. The health care organization should determine the hazard exposure to the perioperative team by the
- job classifications that place team members at risk,[128]
- number of procedures where surgical smoke is generated,[128]
- percentage of surgical procedures where surgical smoke is not evacuated,
- type of energy-generating devices used,
- number of smoke evacuators available,
- number of ORs needing smoke evacuators, and
- current usage of smoke evacuation soft goods (ie, smoke evacuator tubing, smoke evacuator filters, in-line filters, laparoscopic filters).[128]

[5: Benefits Balanced with Harms]

I.b. The health care organization should use OSHA's hierarchy of controls[40] to reduce the perioperative team's exposure to surgical smoke and establish safe practices. The hierarchy of controls includes
- eliminating the hazard,
- using engineering controls (eg, room ventilation[115] of 20 total air exchanges per hour[42,129,130]),
- using work practice controls (eg, smoke evacuation[53,54,56,115]),
- using administrative controls (eg, policies and procedures, education and training), and
- using PPE.[131]

[3: Moderate Evidence]

Controlling exposures to hazards and toxic substances is the fundamental method of protecting workers. A hierarchy of controls is used as a means of determining how to implement feasible and effective controls. The OSHA hierarchy of controls is a systematic approach that can be used to identify the most effective method of risk reduction. Where possible, elimination or substitution is the most effective approach followed by use of engineering controls. Engineering controls are physical changes to the work environment that will minimize the health care worker's exposure to the hazard. Work practice controls establish efficient processes and procedures. Administrative controls (eg, policies and procedures) are used in conjunction with the other controls that more directly reduce or eliminate exposure to the hazard. Personal protective equipment reduces exposure to the risks and is the last line of defense against exposure to surgical smoke when exposure cannot be reduced through a higher level of control.[40]

I.b.1. When possible, the perioperative team should use the highest level of control.[39] If the hazard (eg, surgical smoke) cannot be eliminated, the team should employ the next level in the hierarchy. *[1: Regulatory]*

I.b.2. Smoke evacuation should be used in addition to room ventilation. *[2: High Evidence]*

The National Institute for Occupational Safety and Health recommends using a combination of ventilation techniques to control the airborne contaminants of surgical smoke. Because general room ventilation of 20 air exchanges per hour is insufficient to capture the contaminants, smoke evacuation (ie, local exhaust ventilation) is also necessary.[115]

I.c. Perioperative team members should wear PPE (ie, respiratory protection) as secondary protection against residual surgical smoke. *[2: High Evidence]*

Standards,[130,132,133] regulations,[128,130] and guidance from professional organizations[27-31,41] recommend using PPE (eg, a fit-tested surgical N95 respirator[128]) as a secondary defense against the inhalation of surgical smoke. General room ventilation and smoke evacuation (ie, local exhaust ventilation) are the first lines of protection against the hazards of surgical smoke.[115] When respiratory protection is required, the minimum

respiratory protection device is a filtering face piece respirator (eg, an N95 respirator).[134]

A fit-tested surgical N95 filtering face piece respirator is a personal protective device that is worn on the face, covers the nose and mouth, and is used to reduce the wearer's risk of inhaling hazardous airborne particles including infectious agents.[76] The NIOSH respirator approval regulation defines the term N95 as a filter class that removes at least 95% of airborne particles during "worse case" testing using a "most-penetrating" sized particle.[135] Filters meeting the criteria are given a 95 rating. Many filtering face piece respirators have an N95 class filter, and those meeting this filtration performance are often referred to simply as "N95 respirators."[135] A surgical N95 respirator is fluid resistant on the outside to protect the wearer from splashes or sprays of body fluids.[40]

A surgical mask is not considered respiratory protection.[40] A surgical mask is a loose-fitting face mask intended to prevent the release of potential contaminants from the user into his or her immediate environment.[40,76] A surgical mask is fluid resistant, providing protection from large droplets, sprays, and splashes of body fluids,[76] but does not give the wearer a reliable level of protection from inhaling small airborne particles.[40] A high-filtration surgical face mask is designed to filter particulate matter that is 0.1 µm in size and larger. Similar to a surgical mask, a high-filtration mask does not create a seal between the face and the mask and may allow dangerous contaminants to enter the health care worker's breathing zone.[41,76,136]

The collective evidence[76,137-141] demonstrates the measurable superiority in protection provided by a surgical N95 respirator compared with high-filtration and surgical masks.

Gao et al[137] investigated the performance of surgical masks (n = 2) and surgical N95 respirators (n = 2) during exposure to surgical smoke. Ten participants were fit tested for the N95 respirators before the experiment. The participants performed surgical dissections on animal tissue in a simulated OR with an electrocautery device to generate surgical smoke. Each of the participants wore all four types of masks or respirators in random order. The generated surgical smoke was sampled in the breathing zone directly outside the mask or respirator to represent the inhalation exposure of an unprotected individual and inside the mask or respirator to represent the inhalation exposure of a protected wearer. The aerosol concentrations and particle size distribution of the inside- and outside-sampled aerosols were measured for 12 minutes each with a particle size spectrometer in combination with an optical particle counter. The simulated workplace protection factor (SWPF) was calculated for the masks and respirators. The SWPF values for both surgical masks were close to 1, indicating essentially no protection. The SWPF values for both N95 masks exceeded 100, the OSHA fit test passing level. The results suggest that surgical masks cannot protect health care workers against surgical smoke but that N95 NIOSH-certified respiratory protection devices can.

The collective evidence demonstrates that surgical masks have inadequate filter performance for aerosols[142,143] and submicron particles[136,144-147] (1 micron = 1 micrometer [µm]).

Rengasamy et al[136] investigated the filtration performance of surgical masks for a wide size range of submicron particles, including the size of many viruses. US Food and Drug Administration (FDA)-cleared masks can be categorized into three barrier types: high, moderate, and low. High and moderate barrier masks are cleared with > 98% filtration efficiency for bacterial filtration efficiency and particle filtration efficiency. Low barrier masks require > 95% for bacterial filtration efficiency only. The researchers tested five models of FDA-cleared surgical masks of all barrier types (n = 1 high barrier type, n = 2 moderate barrier type, and n = 2 low barrier type) for room air particle penetrations under constant and cyclic flow conditions. The following tests were performed:

- room air particle penetration at constant flow condition,
- room air particle penetration as a function of particle size,
- particle penetration measurement at cyclic flow conditions,
- polydisperse sodium chloride aerosol penetration measurement,
- monodisperse aerosol test method, and
- effect of isopropanol treatment on monodisperse aerosol penetrations.

Results of this study showed a wide variation in filtration performance. The researchers concluded that the wide variation in penetration levels for room air particles, which included particles in the viruses size range, confirms that surgical masks should not be used as respiratory protection.[136]

Oberg and Brosseau[148] evaluated nine types of surgical masks for filtration performance and facial fit. The types included surgical, laser, and procedure masks that were cupped, flat, and duckbilled with ties and ear loops. The masks' filter efficiency varied widely from very low to high. Facial fit was evaluated quantitatively and qualitatively. When filter performance and facial fit were evaluated, none of the surgical masks met the qualifications of respiratory protection devices.

I.c.1. A fit-tested surgical N95 filtering face piece respirator should be used during higher-risk, aerosol-generating procedures and procedures on patients with known or suspected aerosol transmissible diseases (eg,

tuberculosis, varicella, rubeola).[134] *[1: Strong Evidence]*

Respiratory protection for aerosol transmissible diseases is based on the pathogen and the anticipated risk associated with the specific procedure.[40] Aerosol-generating procedures (eg, endotracheal intubation, bronchoscopy) generate higher concentrations of airborne particles and aerosol transmissible disease pathogens.[40] The Centers for Disease Control and Prevention[134] recommends that all team members present during cough-inducing or aerosol-generating procedures on patients with suspected or confirmed tuberculosis use respiratory protection.

Chen et al[149] measured the filtration efficiencies of a single-use submicron surgical mask and three types of respirators against aerosolized mycobacteria. In a specially designed enclosed test apparatus, an aerosol was generated with a known concentration of *Mycobacterium chelonae*, a surrogate for *Mycobacterium tuberculosis*. The researchers used Andersen samplers to measure aerosol concentrations upstream and downstream of the test masks and respirators. Mean percentage efficiencies for *Mycobacterium chelonae* ranged from 97% for the molded surgical mask and one type of respirator to 99.99% for the high-efficiency particulate air (HEPA) respirator. An analysis of variance demonstrated that the effect of mask or respirator type was significant. The researchers concluded that their evaluations could lead to development of an effective and practical device that would protect the health care worker without compromising patient care or safety.

I.c.2. In disease transmissible cases (eg, HPV),[10,81,94] the perioperative team may use a fit-tested surgical N95 filtering face piece respirator in conjunction with smoke evacuation. *[3: Moderate Evidence]*

A fit-tested surgical N95 filtering face piece respirator does not replace the need to use a smoke evacuation system as the first line of protection against the hazards of surgical smoke.

Recommendation II

The perioperative team should evacuate all surgical smoke.

The collective evidence[3,17,18,52,61,77,80,82,92,110,111,133,150-165]; standards[132,133]; regulations[128,130]; and guidance from NIOSH,[42,53,54,56,64,115] the Healthcare Infection Control Practices Advisory Committee,[166] and professional organizations[27-31] indicates that evacuating surgical smoke protects patients and health care workers from the hazards of surgical smoke (Table 3).

II.a. The perioperative team should use a smoke evacuation system (eg, smoke evacuator, in-line filter) to evacuate all surgical smoke. *[2: High Evidence]*

The National Institute for Occupational Safety and Health recommends using smoke evacuation systems to reduce potential acute and chronic health risks to health care personnel and patients.[115] The hazards of surgical smoke exposure to the perioperative team are respiratory, chemical, biologic (eg, blood, virus, bacteria), carcinogenic, mutagenic, and cytotoxic. Repeated exposure to the contents of surgical smoke may be cumulative[7,8,50] and increases the possibility of developing adverse effects.[44,52] Surgical smoke exposure risks to patients during minimally invasive procedures[12-18] include loss of visibility in the surgical field with potential to delay the procedure,[19-22] port site metastasis,[23] exposure to carbon monoxide,[22,24,25] and increased levels of carboxyhemoglobin,[22,24] and risks during open procedures include potential respiratory inflammation[165] and postoperative refractive errors.[167]

In Zgierz, Poland, Dobrogowski et al[52] conducted a study to identify and quantitatively measure selected chemical substances in surgical smoke and to assess the risk of the chemicals to medical personnel. The researchers collected air samples in the OR during laparoscopic cholecystectomy procedures. A complete qualitative and quantitative analysis of the samples showed the presence of aldehydes, benzene, toluene, ethylbenzene, xylene, ozone, and dioxins in concentrations lower than the hygienic standards used in the European Union. The researchers noted that the synergistic and antagonistic interactions of these substances have not been studied and are difficult to predict, and they concluded that surgical smoke should be evacuated to protect the OR team from the toxic and possibly carcinogenic, mutagenic, and genotoxic effects.

Moot et al[61] used selected ion flow tube mass spectrometry to analyze the composition of volatile organic compounds in diathermy plume produced during abdominal surgery. The researchers identified hydrogen cyanide, acetylene, and 1,3-butadiene in the plume. They concluded that although there is no evidence of adverse health effects from volatile organic compounds in surgical smoke plume, there is no evidence to indicate that it is safe to breathe smoke plume; thus, they recommended using smoke evacuators.

Respiratory Hazards

The size (ie, aerodynamic diameter) of the particles in the surgical smoke directly influences the type of adverse respiratory health effects experienced by the perioperative team.[19,41,66,69,73,76,102,123,168-171] Particle size depends on the type of surgical device generating the surgical smoke.[1,19,20] The ESU creates particles with the mean aerodynamic size

TABLE 3. HEALTH EFFECTS OF CHEMICALS IN SURGICAL SMOKE[1,2]

Chemical	Health Effects
Acetaldehyde	Eye, skin, and respiratory irritation; eye and skin burns; dermatitis; conjunctivitis; cough; central nervous system (CNS) depression; delayed pulmonary edema; carcinogenic effects (nasal cancer)
Acetonitrile	Eye, skin, and nose irritation; cyanosis; cardiac and respiratory arrest
Acetylene	Headache, dizziness, reduced visual acuity, poor judgment, weakness, unconsciousness, rapid pulse and respiration, cyanosis, cardiac and respiratory symptoms related to oxygen deficiency
Acrolein	Eye, skin, and upper respiratory irritation; decreased pulmonary function; delayed pulmonary edema; chronic respiratory disease; possible increased blood clotting time; liver and kidney damage
Acrylonitrile	Eye and skin irritation, asphyxia, headache, sneezing, nausea, vomiting, lassitude, dizziness, skin vesicles, scaling dermatitis, CNS impairment, potential carcinogenic effects (brain tumors, lung and bowel cancer)
Anthracene	Skin damage, burning, itching, edema, headaches, nausea, loss of appetite, stomach and intestinal swelling, slowed reaction time, weakness, reduced serum immunoglobulins
Benzaldehyde	Acute eye and skin irritation and redness
Benzene	Eye, skin, nose, and respiratory irritation; dizziness; headache; nausea; staggered gait; anorexia; weakness; fatigue; dermatitis; bone marrow depression; potential carcinogenic effects (leukemia)
Benzonitrile	Eye and skin irritation
Butadiene (1,3 Butadiene)	Eye, nose, and throat irritation; drowsiness; dizziness; carcinogenic effects (leukemia and lymphoma)
Carbon monoxide	Headache, tachypnea, nausea, vomiting, fatigue, dizziness, confusion, hallucinations, cyanosis, cardiac dysrhythmias, myocardial ischemia, lactic acidosis, syncope, convulsion, coma Symptoms depend on the degree of exposure and susceptibility of the individual.
Creosol	Respiratory, eye, and skin irritation; cytotoxic effects; corrosive effects
Cyclohexanone	Respiratory irritation (potent irritant)
Decane	Eye, skin, and respiratory irritation; headache; dizziness; stupor; incoordination; loss of appetite; nausea; dermatitis
1-Decene (hydrocarbon)	Eye and respiratory irritation; may be a slight anesthetic at high concentrations
Ethane	Asphyxiation (simple asphyxiant)
Ethanol	Eye, skin, and nose irritation; headache; drowsiness; lassitude; narcosis; cough; liver damage; anemia; reproductive and teratogenic effects
Ethylene	Headache, muscular weakness, drowsiness, dizziness, unconsciousness
Ethyl benzene	Eye, throat, skin, and mucous membrane irritation; dizziness; dermatitis; narcosis; coma
Formaldehyde	Eye, nose, throat, and respiratory irritation; coughing; bronchospasm; lacrimation; cough; wheezing; potential carcinogenic effects (nasal cancer)
Furfural	Eye, skin, and upper respiratory irritation; sore throat; cough; bronchospasm; shortness of breath; headache; vomiting; dermatitis
Hydrogen cyanide	Asphyxiation, lassitude, headache, confusion, nausea, vomiting, increased rate and depth of respirations, slow and gasping respirations, thyroid and blood changes
Isobutene	Dizziness, drowsiness, dullness, nausea, unconsciousness, vomiting
Isopropanol	Eye, nose, and throat irritation; drowsiness; dizziness; headache
Methane	CNS depression, cardiac sensitization

continued on next page

TABLE 3 CONTINUED. HEALTH EFFECTS OF CHEMICALS IN SURGICAL SMOKE[1,2]

Chemical	Health Effects
4-Methyl phenol (*p*-cresol)	Eye, skin, and mucous membrane irritation; CNS effects; confusion; depression; respiratory failure; dyspnea; irregular rapid respiration; weak pulse; eye and skin burns; dermatitis; lung, liver, kidney, and pancreatic damage
2-Methyl propanol	Eye, skin, and throat irritation; headaches; drowsiness
Phenol	Eye, nose, and throat irritation; anorexia; weight loss; lassitude; muscle ache; pain; dark urine; cyanosis; liver and renal damage; skin burns; dermatitis; tremor; convulsions; twitching
Polycyclic aromatic hydrocarbons	Eye and respiratory irritation, dermatitis, conjunctivitis, increased risk of certain cancers
Propylene	Drowsiness, dizziness, unconsciousness
Pyridine	Eye irritation, headache, anxiety, dizziness, insomnia, nausea, anorexia, dermatitis, liver and kidney damage
Styrene	Eye, nose, and respiratory irritation; headache; lassitude; dizziness; confusion; malaise; drowsiness; unsteady gait; defatting dermatitis; possible liver injury; reproductive effects
Toluene	Eye and nose irritation, lassitude, confusion, euphoria, dizziness, headache, dilated pupils, lacrimation, anxiety, muscle fatigue, insomnia, paresthesia, dermatitis, liver and kidney damage
Xylene	Eye, skin, nose, and throat irritation; dizziness; excitement; drowsiness; incoordination; staggering gait; anorexia; nausea; vomiting; abdominal pain; dermatitis

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of < 0.1 µm, laser particles are ~ 0.31 µm, and ultrasonic scalpel particles are 0.35 µm to 6.5 µm.[1,19,144] Particle size affects how far the particle can travel in the respiratory system.[19,76] Particles that are 5 µm or larger settle in the walls of the nose and pharynx; particles 3 µm to 5 µm settle in the trachea; particles 1 µm to 3 µm settle in the bronchus and bronchioles; and particles smaller than 1 µm can penetrate to the alveoli (Figure 2).[112,123,145] Particles smaller than 5 µm are categorized as lung-damaging dust,[172] as they can penetrate to the deepest areas of the lung and obstruct gas exchange.[19,76,168]

Näslund Andréasson et al[67] compared the amount of airborne particles and UFPs generated during peritonectomy with the amount of airborne particles and UFPs generated during colon and rectal cancer surgery. Personal and stationary samplings of UFPs were taken during peritonectomy procedures (n = 14) and colon and rectal cancer surgeries (n = 11). The median, maximum, and cumulative UFP levels for personal and stationary samplings were higher during the peritonectomy procedures than during the colon and rectal cancer surgeries. The mean cumulative levels were statistically significant for both the personal and stationary samplings. In discussing the results, the researchers compared the cumulative concentrations of UFP to smoking cigarettes or frying beef. They concluded that high levels of UFPs generated by electrocautery devices can be a health risk, and this warrants further investigation.

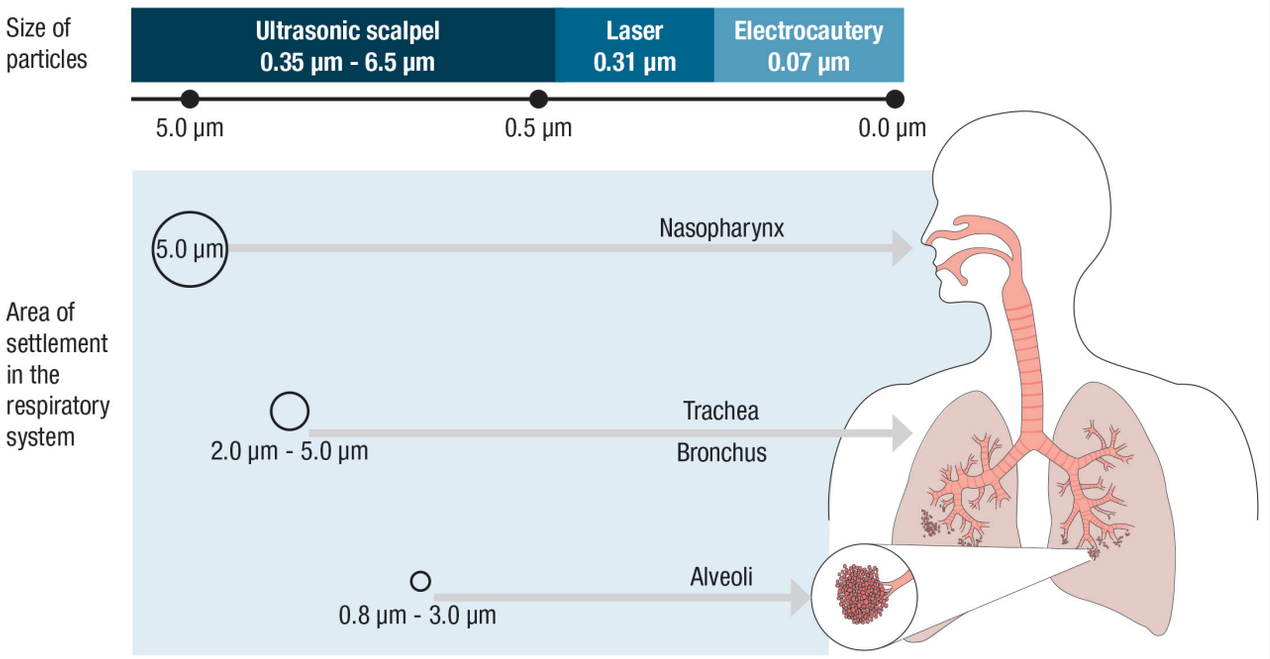
Chemical Hazards

The chemical content of surgical smoke varies by the type of tissue treated (eg, muscle, fat),[19,44,47,48,55,57,60,61,122,123] type of device (eg, laser,[49] ESU) used,[1,19,43,48,57,60,118,123] and duration of the procedure.[55]

Hollman et al[119] conducted an assay of surgical smoke generated during a reduction mammoplasty procedure. Monopolar electrocautery was used for dissection and resection, which resulted in intense smoke production. The researchers collected smoke samples (N = 25) whenever the electrocautery was in use. Laser spectroscopy was used to determine the gas components and corresponding concentration in the smoke samples collected. Eleven gases (ie, 1-ethenyl-3-methyl-benzene; 1,3-butadiene; propanenitrile; toluene; thiocyanic acid, methyl ester; 1-heptene; ethylene; ammonia; 1-decene; 2-furancarbox aldehyde; methylpropene) were identified and quantified. The researchers concluded that there is no doubt that surgical smoke generated by electrocautery is a potential health danger to the OR team. The degree of the threat is unclear. Follow-up studies are needed to determine particulate material, biological impurities, and gaseous components.

Hassan et al[150] conducted a prospective study to quantify the exposure of the surgeon and the patient to known chemical toxins in electrocautery smoke, and to determine whether there were qualitative or quantitative differences in exposure

FIGURE 2. SURGICAL SMOKE PARTICLE SIZE



during laparoscopic or open ileal loop pouch anastomosis. The researchers measured the surgeon's exposure to benzene, toluene, xylene, acetone, and styrene. They tested the patient's blood preoperatively within 6 hours of surgery and at the end of the procedure for benzene, ethyl benzene, toluene, xylene, carboxyhemoglobin, and cyanide. During the laparoscopic procedures, a smoke filter was used to maintain visibility, and during the open procedures, the electrocautery smoke was suctioned by the first assistant. The samplings of the surgeon's exposure were all negative. The patients' preoperative and postoperative levels of cyanide, carbon monoxide, benzene, ethyl benzene, toluene, and xylene were below standard detectable levels in the laparoscopic and open procedures. The researchers concluded that the methods (ie, suction devices) used to remove smoke from the surgical field and the OR air exchanges of the HVAC system were effective and minimized exposure of the health care team and the patient to the chemicals in surgical smoke. Additional qualitative and quantitative studies of the contents of electrocautery smoke are needed as well as technology that more efficiently and effectively evacuates surgical smoke from the surgical site and the OR environment.

In a study to determine the chemical composition of surgical smoke, Sagar et al[45] collected samples of surgical smoke generated by electrocautery during colorectal surgery. The sampling tube was attached near the end of the electrocautery pencil or held in the plume above the pencil. The researchers analyzed the collected smoke samples for PAHs, nitrosamines, nitrates, nitrites, and volatile organic compounds by using high-performance liquid chromatography, gas chromatography with a thermal energy analyzer, ion chromatography, and mass spectrometry. The electrocautery smoke contained significant levels of benzene, ethyl benzene, styrene, carbon disulphide, and toluene. Benzene, a known carcinogen, was detected in significant quantities (71 µg/m^3). The substances detected cause eye irritation, dermatitis, central nervous system effects, and hepatic and renal toxicity. The researchers concluded that additional studies are needed to determine the extent of exposure to the entire OR team and to develop methods to reduce the health risks.

Petrus et al[43] quantitatively analyzed surgical smoke produced in vitro by vaporization of fresh animal tissue with a CO_2 laser in a closed nitrogen atmosphere. The concentrations of acetonitrile, acrolein, ammonia, benzene, ethylene, and toluene in surgical smoke were determined with laser photoacoustic spectroscopy. The researchers investigated different types of tissue (ie, pig kidney, muscle, skin, heart) at a laser vaporization power of 10 watts and 15 watts with exposure times of 5 seconds and 15 seconds. Several smoke samples were collected, and the average gas concentrations were measured. The concentrations of the six gases measured were acetonitrile 190 ppm, acrolein 35 ppm, ammonia 25 ppm, benzene 20 ppm, ethylene 0.410 ppm, and toluene 45 ppm. The researchers concluded that the concentrations of all six gases increased depending on the laser power, exposure time, and type of tissue and

that the laser photoacoustic spectroscopy system was efficient in analyzing a multicomponent gas mixture.

Carcinogenic Hazards

The evidence is inconclusive as to whether exposure to surgical smoke places perioperative team members at increased risk of developing cancer.[23,62,111-113,173-175]

Tseng et al[62] investigated particle number concentrations, size distribution, and gaseous and particle phase PAHs as the tracers of surgical smoke in the OR. Through their investigation of PAH concentrations for different surgical personnel, the potential cancer risk can be estimated for OR team members exposed to electrosurgery smoke. The researchers chose mastectomy procedures because of procedure length and high electrocautery use. During 14 mastectomy procedures, samples from the breathing zones of the surgeon and anesthesia provider were collected at 5-minute intervals. The majority of the airborne particles (70%) were 0.3 µm in size.

The downward flow of air (ie, positive pressure) from the OR ceiling distributed the smoke into the surrounding environment, exposing all personnel in the room instantaneously. The particle and gaseous PAH concentrations for the surgeon and anesthesia provider increased 40 to 100 times over the initial baseline measurements. The surgeon was exposed to the highest level of PAHs, approximately 1.5 times higher than the anesthesia provider. Although the anesthesia provider's levels were less than the surgeon's, longer hours working in the OR increased the risk. The researchers concluded that the submicron particles in the smoke contained carcinogenic chemicals and could threaten the health of the OR team through respiration of the particles. Using the toxicity equivalency factor, the average cancer risk in a 70-year lifetime for the surgeons and the anesthesia provider was calculated to be 117×10^{-6} and 270×10^{-6}, respectively, which are significantly higher the World Health Organization recommendation of 1×10^{-6}.[62]

In et al[111] conducted a two-part in vitro experiment to determine whether viable cells were present in surgical smoke. If viable tumor cells were found, the in vivo study portion evaluated their carcinogenicity. Viable cells were identified in the smoke at 5 cm from the ultrasonic scalpel. No viable cells were detected in the smoke from the ESU or radio-frequency ablation device. The viable cells were injected on both sides of the lower back of 20 mice. After 2 weeks, there was tumor growth in 16 of the 40 injection sites. Biopsies for morphological assessment showed highly mitotic cells, including irregularly shaped nuclei consistent with malignant tumors. The results suggest that malignant cells can be aerosolized when the ultrasonic scalpel is used on tumor-bearing tissue and may be the reason for tumor recurrence at a port site remote from the original tumor. The researchers concluded that smoke from an ultrasonic scalpel may contain viable tumor cells, and there is a theoretical risk of transfer of the viable tumor cells to anyone close to the surgical procedure.

Mowbray et al[112] conducted a systematic review of the literature to evaluate the properties of surgical smoke and the evidence of the harmful effects to OR team. The authors reviewed 20 studies that met the inclusion criteria for documentation of the contents of surgical smoke during human surgical procedures, methods to analyze the smoke, implication of smoke exposure, and type of energy device. The authors concluded that their review confirmed surgical smoke contains potentially carcinogenic compounds small enough to be respirable and reach the lower airways. The potential for harm is present, but the risk to the OR personnel remains unproven.

Mutagenic Hazards

Several studies[5,147,155,176,177] have demonstrated the mutagenicity of surgical smoke. Gatti et al[146] collected multiple air samples in the OR during reduction mammoplasty procedures using electrocautery for dissection and excision of the breast tissue. The OR samples were collected approximately 2.5 ft to 3 ft above the surgical field. Control air samples were taken in a separate room. All of the samples were tested for mutagenic activity in standard tester strains TA98 and TA100 of *Salmonella typhimurium* using the *Salmonella* microsomal microsuspension test. The results showed the air samples were mutagenic to the TA98 strain of *Salmonella typhimurium*. The TA100 strain of *Salmonella typhimurium* did not appear to be significantly altered by the smoke. The researchers concluded from this preliminary study that the smoke produced by the electrocautery during reduction mammoplasty is mutagenic. Mutagenic potential may vary among patients. Safe levels of ambient mutagens have not been determined.

To test the mutagenic activity of surgical smoke condensates, Tomita et al[5] used a CO_2 laser to irradiate and an ESU to cauterize excised canine tongue. The researchers tested the generated smoke with the microbial strains TA98 and TA100 of *Salmonella typhimurium*. The laser condensates showed mutagenicity on TA98 in the presence of S9 mix. The S9 mix contained 50 µmoles sodium phosphate buffer, 4 µmoles magnesium chloride, 16.5 µmoles potassium chloride, 2.5 µmoles glucose-6 phosphate, 2 µmoles nicotinamide adenine dinucleotide phosphate, and 150 µL of S9 fraction (prepared from rat liver

pretreated with polychlorobiphenyl) in a total volume of 0.5 mL. The ESU condensates exhibited mutagenic activity on both strains in the presence of S9 mix. The mutagenic ability of laser condensates was one-half that of the ESU condensates for the microbial strain TA98. The microbial strain TA98 of *Salmonella typhimurium* was 10 times more sensitive than microbial strain TA100 of *Salmonella typhimurium* to the condensates.

The ESU may be more favorable for the generation of mutagens than laser irradiation. The mutagenic potency of the laser condensates was comparable to that of cigarette smoke. The researchers collected about 40 mg of laser and ESU condensates from 1 g of vaporized or cauterized tissue. This amount of laser condensate was equivalent to that from three cigarettes, and this amount of ESU condensate was equivalent to that from six cigarettes. The researchers concluded that more research is needed to evaluate the hazards of laser and ESU smoke on human health and, unless proven otherwise, there is a potential health risk to surgeons, anesthesia providers, nurses, and patients.[5]

Hill et al[154] studied six human and 78 porcine tissue samples to find the mass of tissue ablated during 5 minutes of monopolar ESU use. They also recorded electronically the total daily duration of ESU use in a plastic surgery OR during a 2-month period. An initial pilot study compared a human tissue sample with the animal model. No difference was found between the two tissue types. Porcine tissue is the most physiologically similar tissue to human tissue. For the human tissue, the mass of the ESU tissue ablation after 5 minutes of continuous cutting ablation was 2.4132 g and the mass after coagulation ablation was 1.5817 g. For the porcine tissue, the mass of the ESU tissue ablation after 5 minutes of continuous cutting ablation was 2.3721 g and the mass after coagulation ablation was 1.5406 g. The mean daily ESU activation time was 12 minutes 43 seconds. Using Tomita's results that 1 g of tissue equals six unfiltered cigarettes,[5] the researchers quantified the environmental OR air pollution. They concluded that the equivalent of 27 to 30 unfiltered cigarettes would need to be smoked in the OR on a daily basis to generate a passive air pollution with an equivalent mutagenicity. The long-term effects of chronic surgical smoke exposure remains unproven. It is known that surgical smoke is mutagenic and contains the same carcinogens as tobacco smoke. The dangers of passive exposure to tobacco smoke are well documented. The researchers recommended using smoke evacuators.

Cytotoxic Hazards

There is limited evidence regarding the cytotoxic effects of surgical smoke.[177-180]

Hensman et al[178] exposed cultured cells for a short period of time to smoke produced in a confined space in vitro to determine whether significant toxicity can occur. The smoke was produced in helium, carbon dioxide, and air-saturated environments. The toxic, infective, and mutagenic risks of surgical smoke during open surgeries are known. In minimally invasive surgery, it is unknown whether the smoke produced in a carbon dioxide-saturated environment may have a different composition. The chemical contents identified in the smoke produced in helium, carbon dioxide, and air were similar in composition. The researchers concluded the ESU smoke generated in a closed environment produced several toxic chemicals. The effect of the toxic chemicals on cell viability, macrophage, and endothelial cell activation is unknown. Until the effects of these toxic chemicals is known, smoke evacuation is recommended during minimally invasive surgery.

Viral Hazards

Several studies[95,181-185] demonstrated a low risk of HPV transmission and subsequent infection.

Kofoed et al[183] investigated the prevalence of mucosal HPV types in medical personnel employed in the gynecology and dermato-venereology departments of multiple Denmark hospitals in relation to occupational exposure to HPV. The participants (N = 287) completed a questionnaire with demographic data, their previous and current work-related HPV exposure, and history of HPV-related disease. The researchers collected oral and nasal mucosa samples from the participants and analyzed the samples using HPV genotyping. In relation to exposure, a mucosal HPV type was found in

- 5.8% of employees with experience in treating genital warts with a laser compared to 1.7% of the participants who did not have this experience;
- 6.5% of participants with experience in treating genital warts with electrosurgery compared to 2.8% of the participants who did not have this experience; and
- 4.7% of participants with experience in treating genital warts with loop electrode excision procedure compared to 4.6% of the participants who did not have this experience.

Physician and non-physician laser personnel who had treated patients with genital warts for at least 5 years had a significantly higher prevalence of mucosal HPV types than personnel who had less than 5 years of experience or no experience treating genital wards with a laser. The researchers found that participating in CO_2 laser or electrosurgical evaporation of genital warts or loop electrode excision of cervical dysplasia did not significantly increase the prevalence of nasal or oral HPV. Mucosal HPV types

are infrequent in the oral and nasal cavities of health care personnel.

Despite the low risk of transmission and subsequent infection with HPV, there have been reported cases of occupational transmission of HPV.[9-11] In 1991, Hallmo and Naess[10] reported the case of a 44-year-old laser surgeon who presented with a large, confluent papillomatous mass in the anterior commissure and along the right vocal cord and four smaller, discrete, smooth papillomas on the left vocal cord. Biopsies of the laryngeal lesions showed squamous papillomas with moderate focal dysplasia. Types HPV-6 and HPV-11 DNA were identified in groups of tumor cells. The surgeon had no known source of infection other than that he had used the Nd:YAG laser for therapeutic procedures involving anogenital condyloma acuminata. Anogenital condylomas harbor HPV types 6 and 11. The authors concluded that any of the surgeon's patients with anogenital warts could have been the source of the surgeon's HPV contamination, and there is a similar risk for laser procedure team members.

Calero and Brusis[9] reported the case of a 28-year-old OR nurse who developed recurrent and histologically proven laryngeal papillomatosis. The nurse's occupational history included assisting on electrosurgical and laser surgical excisions of anogenital condylomas. After a virological institute confirmed the high probability of correlation between the occupational exposure and laryngeal papillomatosis, the nurse's condition was accepted as an occupational disease. Hallmo and Naess[10] and Calero and Brusis[9] concluded that the occupational transmission risk of HPV is low when recommended protective measures (eg, smoke evacuation) are employed.

Rioux et al[11] described the cases of HPV-16 positive oropharyngeal squamous cell carcinomas in two surgeons with long-term histories of occupational laser plume exposure to HPV. A 53-year-old gynecologist sought consultation for a lesion on his right tonsil and a lump in the right side of his neck. The biopsy of the right tonsil confirmed invasive squamous cell carcinoma of moderate to poor differentiation. The lesion was positive for HPV-16 by hybrid capture assay. The patient was a non-smoker who consumed alcohol occasionally, was in a monogamous relationship, and whose partner tested negative for HPV. The only identifiable risk factor for oropharyngeal cancer and HPV was occupational exposure to HPV-positive laser plume. The surgeon performed more than 3,000 laser ablations and loop electrosurgical excisions for dysplastic cervical and vulvar lesions over 20 years.

The second case was a 62-year-old gynecologist who sought consultation for a foreign body sensation in his throat. A biopsy of the base of his tongue was positive for squamous cell carcinoma and HPV-16. The surgeon was a non-smoker who consumed alcohol occasionally and had been married twice. The surgeon's occupational history consisted of performing weekly laser ablations with a CO_2 laser for 15 years and performing loop electrosurgical excision procedures for 15 years. The authors suggested prophylactic HPV vaccination against oncogenic HPV strains to prevent infection and reduce the risk of oropharyngeal cancer.

In a university laboratory research center, Garden et al[81] investigated whether laser-generated plume from infected animal tissue (ie, bovine papillomavirus [BPV]-induced cutaneous fibropapilloma) can reproduce disease. The researchers evaluated three laser settings, suctioned and collected the laser plume at each setting, and re-inoculated the laser plume onto the skin of three calves. All of the laser plume samples at the three laser settings contained BPV DNA. Two calves developed marked lesions at the sites of BPV inoculum, and the third calf developed minimal growth. The histological evaluation of the excised laser-plume induced lesions was typical of BPV fibropapillomas. The DNA extracts from each of the three induced tumors contained high levels of BPV DNA, thus confirming that the lesions resulted from the BPV infection. The researchers found the lesions induced by the laser plume were identical to the original lesions based on the histopathological and viral typing.

The evidence conflicts on whether pathogenic virus transfer occurs during excimer laser treatment of corneal tissue.[85,186,187]

Hagen et al[187] developed a model system to test the possibility of virus transmission during excimer laser treatment through airborne excimer laser debris. An excimer laser was used to ablate a culture plate infected with psuedorabies virus. Psuedorabies virus is a porcine enveloped herpes virus, similar in structure and life cycle to HIV and the herpes simplex virus. In vitro transfer of viable psuedorabies virus by excimer laser plume did not appear to occur. The researchers concluded that the surgeon and team members are at low risk of infection by enveloped viruses (eg, HIV, herpes simplex) transmitted by the excimer laser plume.

In 1997, Taravella et al[186] used an excimer laser to ablate fibroblasts infected with attenuated varicella-zoster virus. The researchers collected the laser plume for PCR analysis and viral cultures. Their results suggested that viral DNA fragments remain intact after ablation but the virus particles capable of causing infection in the fibroblast culture do not. They concluded that attenuated varicella-zoster virus does not seem to survive excimer laser ablation, and further research is needed to determine whether

other viruses could remain infectious after exposure to excimer laser radiation.

In a subsequent experimental study in 1999, Taravella et al[85] used an excimer laser to ablate fibroblasts infected with oral polio vaccine virus. The researchers collected the laser plume for viral cultures. The cultures were positive for the virus. The researchers also analyzed the role of virus size and its ability to remain infectious after excimer laser ablation. The oral polio virus is approximately 30 nm in size compared with 200 nm for the herpes virus family. The results suggested that smaller viruses might be able to escape ablation, whereas larger viruses may not. The researchers concluded that the oral polio virus can survive excimer laser ablation and that whether other viruses, such as HIV, can withstand ablation and remain infectious needs to be determined.

Bacterial Hazards

Capizzi et al[98] conducted a prospective study to analyze the potential bacterial and viral exposure to OR personnel from the laser smoke plume generated by CO_2 laser resurfacing. During 13 consecutive laser resurfacing procedures, the researchers captured the smoke plume using a smoke evacuator with a HEPA filter. Before the resurfacing procedures, the room air was filtered with the smoke evacuator. The HEPA filter served as the control. Two bacterial and two viral cultures were collected per filter. Bacterial cultures were incubated for 14 days if results were negative, and the viral cultures were incubated for 28 days if the results were negative. There was no growth from any of the viral cultures. Five patients had a bacterial culture that grew +1 coagulase-negative *Staphylococcus*. Two of these five patients also had a concomitant bacterial growth of either *Corynebacterium* or *Neisseria*. The researchers concluded that viable bacteria exist within the laser smoke plume generated during laser resurfacing. Additional research is needed to define the exposure risk associated with patients who have hepatitis, HIV, and antibiotic-resistant bacteria.

Patient Health Effects

Two studies[165,167] report potential hazardous effects to patients from surgical smoke exposure.

Freitag et al[165] investigated the harmful effects of surgical smoke inhalation for the patient and the OR team in an animal study. To simulate a single patient exposure of the respiratory system during a procedure, the researchers measured the effects of one 10-minute exposure on airway resistance, gas exchange, and mucociliary clearance rate in the trachea. To simulate the repetitive exposures of surgical smoke inhalation by the OR team, the researchers measured the effects of three separate 10-minute exposures on airway resistance, gas exchange, and mucociliary clearance rate in the trachea. They found a decrease in arterial partial pressure of oxygen after smoke inhalation. Tracheal mucous velocity was significantly depressed in a dose-dependent manner with increasing smoke exposure. Results of bronchoalveolar lavages showed smoke inhalation induced a severe inflammation with increases of inflammatory cells. The researchers concluded that the surgeon should be aware that inhalation of laser-generated smoke may cause transient hypoxia, depression of lung defense mechanisms, and delayed airway inflammation.

Charles[167] retrospectively studied the effects of laser plume evacuation on laser in-situ keratomileusis (LASIK) outcomes in 199 patients (n = 82 with no evacuation, n = 117 with plume evacuation). There were no statistical differences in the frequency of corneal abrasion, flap slippage, or the level of postoperative debris. A significant difference was noted in postoperative residual refractive error and uncorrected visual acuity. In the no evacuation group, 90% had uncorrected visual acuity of 20/40 or better, 68% saw 20/25 or better, and 59% saw 20/20 or better. In the plume evacuation group 96% had uncorrected visual acuity of 20/40 or better, 89% saw 20/25 or better, and 74% saw 20/20 or better. Charles concluded that using plume evacuation for LASIK procedures improved refractive and uncorrected visual acuity outcomes following the procedure.

II.a.1. The decision to evacuate or not evacuate surgical smoke should not be made at the discretion of an individual practitioner.[32] *[3: Moderate Evidence]*

The patient and other perioperative team members are continually exposed to the hazards of surgical smoke.[32]

II.a.2. A smoke evacuator with a 0.1 µm filter (eg, ultra-low particulate air [ULPA]) should be used when surgical smoke is anticipated.[27,30,31,115,128,132] *[2: High Evidence]*

Electrosurgery generates the smallest aerodynamic size particles (< 0.07 µm to 0.1 µm); laser tissue ablation creates larger particles (~ 0.31 µm); and ultrasonic scalpels create the largest particles (0.35 µm to 6.5 µm).[19] An ULPA filter has an a 99.999% efficiency.[188]

II.a.3. When using a medical-surgical vacuum system, a 0.1 µm in-line filter (eg, ULPA) should be in place between the suction wall connection and the suction canister.[30,31,115,128,130,132,133] *[2: High Evidence]*

An in-line 0.1 µm filter captures airborne contaminants in surgical smoke.[115]

II.a.4. A medical-surgical vacuum system (ie, wall suction) may be used to evacuate small

amounts[188] of surgical smoke as defined by the health care organization's policy and procedures. *[5: Benefits Balanced with Harms]*

Low suction flow rates[128] associated with medical-surgical vacuum systems limit their efficiency in evacuating surgical smoke, making them suitable only for the evacuation of small amounts of smoke.[130,188]

II.a.5. Preventative maintenance for a centralized stationary smoke evacuation system should include flushing of the smoke evacuator lines according to the manufacturer's instructions.[130] *[4: Limited Evidence]*

A centralized stationary smoke evacuation system is permanently installed in mechanical spaces and provides evacuation to several points of use.[128] The scavenged, filtered air is exhausted outside of the building.[128] Regular maintenance of the smoke evacuator lines prevents particulate matter buildup or contamination of the suction line.

II.a.6. Smoke evacuation units and accessories should be used according to manufacturers' written instructions (eg, filter change, distance of the capture device from the generation of surgical smoke).[30,31,115,130] *[2: High Evidence]*

II.b. The capture device (eg, wand, tubing) of a smoke evacuation system should be positioned as close to the surgical site as necessary to effectively collect all traces of surgical smoke. *[2: High Evidence]*

Standards[130,132] and guidance from NIOSH[115] and professional organizations[27,30,31] recommend that the surgical smoke capture device be kept as close as possible to the surgical site; NIOSH[115] recommends that the device be kept within 2 inches (5.08 cm) of the surgical site. Capture performance is affected by the smoke evacuator flow rate,[188,189] distance of the evacuator nozzle to the surgical site,[188-190] tubing size, and amount of smoke generated.[189]

If there is a detectable odor when a smoke evacuation system is in use, it is a signal that

- smoke is not being captured at the site where it is being generated,
- there is inefficient air movement through the suction or smoke evacuation wand, or
- the filter has exceeded its usefulness and should be replaced.[191]

In a preliminary study to simulate smoke production conditions during CO_2 laser surgery, Smith et al[190] measured smoke concentrations at 6 inches, 3 feet, and 4 feet from the site of the laser interaction with the tissue. The 6-inch distance represented the location of the surgeon and other personnel performing the surgery. The 3- and 4-feet distances were used to monitor the areas in which other personnel might be present in the room and to estimate background concentrations of the smoke in various parts of the room. The nozzle of the smoke evacuator was located at 2 inches, 6 inches, and 12 inches to measure the relative effectiveness of the smoke evacuation system. The researchers used aerosol and dust monitors to measure the relative concentration of the smoke with a scale of zero to 20. When the smoke was not evacuated, the relative concentration of smoke at 6 inches was high, ranging from 10 to 20, compared to the background relative concentration of zero to 1, demonstrating a clear indication to use a smoke evacuator. When the smoke evacuator nozzle was 2 inches from the laser interaction site, the nozzle completely collected the smoke when the evacuator was activated. At 6 inches, the smoke collection was not complete and the relative concentrations rose as high as 8. The results at 12 inches was qualitatively similar to the results at 6 inches except that background smoke levels increased. The researchers concluded that positioning the nozzle of the smoke evacuator at a distance of 2 inches is adequate for smoke capture. Distances greater than 2 inches may result in exposure to high concentrations of smoke for personnel working near the surgical site and are likely to an increase the background concentrations in the room.

In a randomized controlled trial, Pillinger et al[162] investigated whether a suction clearance device would reduce the amount of smoke reaching the surgeon's mask compared to no smoke evacuation. All of the patients underwent either thyroid or parathyroid surgery with a standard anterior cervical collar incision and division of the strap muscles. The amount of smoke reaching the level of the surgeon's mask was measured with an aerosol monitor. Smoke evacuation was used for the patients in the experimental group (n = 15), and no smoke evacuation was used for the patients in the control group (n = 15). Baseline measurements were taken before the patients entered the OR, continuously during surgery, and postoperatively after the patient left the OR for the postanesthesia care unit.

Use of smoke extraction resulted in a significant reduction in the mean amount of smoke detected at the level of the surgeon's mask. In surgeries that used no smoke evacuation, the mean amount of smoke detected at the surgeon's mask was 137 $\mu g/m^3$. In surgeries that used smoke evacuation, the mean amount of smoke detected at the surgeon's mask was 12 $\mu g/m^3$. Use of smoke extraction resulted in a significant reduction in the maximum amount of smoke detected at the level of the surgeon's mask (control group 2411 $\mu g/m^3$; experimental group 255 $\mu g/m^3$). Clearing the smoke improved visibility of the surgical field and reduced the characteristic diathermy smell. The researchers concluded

that evacuation of surgical plume resulted in a significant reduction in the amount of smoke reaching the level of the surgeon's mask and that the use of smoke evacuation is advisable.[162]

II.b.1. The smoke evacuation system (eg, smoke evacuator, medical-surgical vacuum with in-line filter) should be activated at all times while surgical smoke is being generated.[115] *[2: High Evidence]*

II.c. The perioperative team should use a smoke evacuation system during minimally invasive procedures. *[3: Moderate Evidence]*

The use of a smoke evacuation system during minimally invasive procedures protects the patient and personnel from the hazards of surgical smoke.[19,24,65,130,192-194] The collective evidence demonstrates that the risks of surgical smoke exposure to the patient are reduced visibility of the surgical site during the procedure,[12-15,17-20,22,195] potential delays during the procedure,[19-22] absorption and excretion of smoke by-products (eg, carbon monoxide,[22,24,25] benzene),[193,196] carboxyhemoglobinemia,[22,24] and port site metastasis.[23,108,197]

Dobrogowski et al[196] assessed patient exposure to organic substances produced and identified in surgical smoke generated during laparoscopic cholecystectomy procedures. The researchers collected urine samples of 69 patients undergoing laparoscopic cholecystectomy procedures before and after surgery and analyzed them for benzene, toluene, ethylbenzene, and xylene. Samples of the gases in the abdominal cavity were obtained from the trocar for identification of the main chemical compounds. The researchers identified about 40 substances, such as aldehydes, unsaturated and saturated hydrocarbons, aromatic hydrocarbons, and dioxins. The concentrations of benzene and toluene were significantly higher in the urine samples after surgery compared with preoperative levels. This is direct evidence that the compounds were produced intraoperatively and absorbed into the blood. The postoperative levels of benzene, a known human carcinogen, were three times higher than before surgery. The researchers concluded that the concentrations of the compounds in the urine were only a small percentage of the total absorbed dose. The mixture of the toxic compounds in the urine can significantly increase the overall toxicity potential caused by the interaction of the compounds. There is also a potential threat from carcinogenic compounds (eg, benzene) despite a short exposure time and low concentrations.

Takahashi et al[17] used an industrial smoke-detection device to evaluate the efficacy of an automatic smoke evacuator in eliminating surgical smoke, including harmful substances, in experimental laparoscopic surgery. Surgical smoke was generated with either a high-frequency ESU or laparoscopic coagulating shears. The participants were divided into a smoke evacuation group and a control group with no smoke evacuation. Ten laparoscopic surgeons independently and subjectively evaluated the laparoscopic field of view. The composition of the smoke was analyzed by mass spectrometry. More than 40 chemical compounds were identified in the smoke. The subjective evaluations indicated a superior field of view in the evacuation group compared with the control group at 15 seconds after activation of the ESU. The estimated volume of residual intra-abdominal smoke after activation of the ESU was significantly lower in the smoke evacuation group. The researchers concluded that the use of an automatic smoke evacuator enhanced the field of view and reduced smoke exposure in experimental laparoscopic surgery.

The evidence conflicts regarding elevated blood[16,22,24,65,194] or intraperitoneal[16,22,65] levels of carbon monoxide posing a patient risk.

In a prospective study, Nezhat et al[194] analyzed the blood samples of patients undergoing laparoscopic procedures with accompanying laser and bipolar ESU smoke generation. Carboxyhemoglobin concentrations were measured with gas chromatography. Preoperatively, the mean carboxyhemoglobin levels were 0.70 ± 0.15%, and postoperatively, the levels were 0.58 ± 0.20%. The decrease was statistically significant. The researchers concluded that carbon monoxide poisoning is not associated with laparoscopic procedures. They attributed the results to aggressive smoke evacuation that minimized patient exposure to carbon monoxide and to active elimination by ventilation with high oxygen concentrations.

To determine the absorption of carbon monoxide from the peritoneal cavity, Ott[24] measured patients' preoperative, intraoperative, and postoperative levels of carboxyhemoglobin. In the control group (n = 25), no lasers or smoke-generating devices were used during the laparoscopic procedure. In the experimental group (n = 25), lasers were used during the laparoscopic procedures. Patients were screened preoperatively for environmental or occupational sources of elevated carbon monoxide. The patients were evaluated for carbon monoxide levels before induction of anesthesia, periodically during the procedure, and postoperatively at 2, 3, 6, 12, and 24 hours. The control group showed no statistical change of preoperative, intraoperative, or postoperative levels of carboxyhemoglobin. Significant elevation of carboxyhemoglobin was found in all 25 of the experimental group members at 10 minutes. The carboxyhemoglobin levels ranged from 2.8% to 18.5% saturation of whole blood and were elevated for as long as 16 hours after the end of the procedure. The patients with the

highest postoperative levels had symptoms of carbon monoxide poisoning (eg, dizziness, nausea, headache, weakness). Ott concluded that patients having laparoscopic procedures with a CO_2 laser were exposed to high levels of carbon monoxide and that smoke evacuation reduces the hazards of carbon monoxide absorption, decreases carboxyhemoglobin formation, and reduces the consequences of acute iatrogenic surgical carbon monoxide exposure resulting from laser-generated smoke during laparoscopic surgery.

II.d. Used smoke evacuator filters, tubing, and wands must be handled using standard precautions, and disposed of as biohazardous waste.[28,30,31,96,115,128,132,198] *[1: Regulatory Requirement]*

Surgical smoke contains potentially hazardous (infectious) material, including viruses[3,80-86] (eg, HPV,[88-95] HIV[96,97]), bacteria,[98-102] blood,[100,105-110] particles,[19,67-77] and cancer cells.[23,111-113]

II.e. A multidisciplinary team that includes perioperative RNs, surgeons, and scrub personnel should select surgical smoke safety equipment to be used in the perioperative setting. Additional team members may include an infection preventionist, engineers (eg, biomedical, HVAC systems), and a materials manager. *[5: Benefits Balanced with Harms]*

Involvement of a multidisciplinary committee allows input from all departments in which the product will be used and from personnel with expertise beyond clinical end users (eg, infection preventionists, materials management personnel). The perioperative RN has a professional responsibility to consider "factors related to safety, effectiveness, efficiency, and the environment, as well as the cost in planning, delivering, and evaluating patient care."[199(p702)] Perioperative RNs play a crucial role in providing practical insight and expertise in the use and evaluation of surgical products.

II.e.1. The multidisciplinary team should evaluate smoke evacuators before purchase.[130] The selection criteria should include the filters (eg, ULPA, carbon),[128,188] minimum flow rate of 25 cu ft/minute, variable flow rate to accommodate various levels of smoke,[128] noise level of 60 A-weighted decibels (dBA) or less, automatic remote activation, the filter monitoring system,[128] and compatibility of products.[188,200] *[3: Moderate Evidence]*

The ULPA filter capture particles in surgical smoke, the carbon filter absorbs the gases in surgical smoke, the minimum flow rate captures the smoke effectively, and the noise level criteria facilitate communication during the procedure.[188]

II.e.2. In collaboration with the perioperative team, the surgical specialists (eg, generalist, otorhinolaryngologist, plastic surgeon, urologist) should evaluate alternative energy-generating devices. *[5: Benefits Balanced with Harms]*

The collective evidence indicates that bipolar instruments,[12,157,201] ultrasonic instruments,[12,50,110,201-207] certain surgical techniques,[208,209] and alternative devices[21,161,185,210-215] generate low amounts of surgical smoke.

Recommendation III

Perioperative team members should receive initial and ongoing education and competency verification on surgical smoke safety.

Initial and ongoing education of perioperative team members facilitates the development of knowledge, skills, and attitudes that affect safe patient care and workplace safety. The health care organization is responsible for providing initial and ongoing education and verifying the competency of its personnel[199]; however, the primary responsibility for maintaining ongoing competency remains with the individual.[216]

Competency verification activities provide a mechanism for competency documentation and help verify that perioperative team members understand the hazards of surgical smoke, evacuation methods, proper equipment usage, and disposal of used tubing and filters.

III.a. The health care organization should establish education and competency verification activities for its personnel and determine intervals for education and competency verification related to surgical smoke safety practices. *[5: Benefits Balanced with Harms]*

III.b. Education and competency verification activities related to surgical smoke safety should include

- defining surgical smoke (ie, the gaseous products of burning organic material created as a result of the destruction of tissue),
- describing critical factors for managing surgical smoke for all procedures that generate surgical smoke,
- identifying sources of surgical smoke (eg, lasers, ESUs, ultrasonic devices, high-speed drills, burrs, saws),
- explaining the effect of particle size on the speed[217] and distance smoke travels,
- describing the health effects of smoke exposure on patients and health care workers,[160]
- selecting smoke evacuation systems and supplies (eg, ESU pencils with incorporated evacuation tubing, in-line filters, smoke evacuator units) in accordance with the procedure being performed,
- testing smoke evacuation equipment before the procedure,
- connecting equipment correctly,
- using smoke evacuation equipment correctly during the procedure,

- using standard precautions to handle used smoke evacuation supplies and discarding biohazardous waste,
- reviewing policies and procedures related to smoke evacuation, and
- participating in quality improvement programs related to the management of surgical smoke as assigned.

[5: Benefits Balanced with Harms]

The evidence indicates there is a lack of knowledge among perioperative team members regarding surgical smoke. Steege et al[32] conducted a web-based survey of members of professional organizations representing health care occupations in which there is routine contact with selected chemical agents, including surgical smoke. Laser surgery and electrosurgery were addressed in separate submodules of the survey. Eligible respondents (N = 4,533) worked within 5 ft of surgical smoke generation during electrosurgery (99%) or laser surgery (31%). The respondents were nurse anesthetists (33%), perioperative nurses (19%), anesthesiologists (21%), surgical technologists (16%), and others (11%). In response to questions on training, 49% of the respondents to the survey laser submodule and 44% of the respondents to the electrosurgery submodule reported that they had never received training on the hazards of surgical smoke.

III.c. Personnel should receive education and complete competency verification activities before new smoke evacuators and accessories are introduced. *[5: Benefits Balanced with Harms]*

Receiving education and completing competency verification activities in advance of changes helps ensure safe practice.

Recommendation IV

Policies and procedures for surgical smoke safety should be developed, reviewed periodically, revised as necessary, and readily available in the practice setting in which they are used.

Policies and procedures regarding surgical smoke safety provide guidance to perioperative team members for creating an environment that reduces the exposure of patients and the perioperative team to surgical smoke. Policies and procedures assist in the development of patient safety, workplace safety, quality assessment, and performance improvement activities. Policies and procedures also serve as operational guidelines used to minimize patients' and perioperative team members' risk for injury or complications, standardize practice, direct personnel, and establish continuous performance improvement programs. Policies and procedures establish authority, responsibility, and accountability within the practice setting. Having policies and procedures in place that guide and support patient care, treatment, and services is a regulatory requirement.[218-221]

IV.a. Policies and procedures for surgical smoke safety should include

- evacuating all surgical smoke generated by energy-generating devices (eg, ESUs, lasers, ultrasonic scalpels/dissectors) during operative or other invasive procedures;
- selecting a smoke evacuation system and supplies (eg, ESU pencils with smoke evacuator tubing, in-line filters, smoke evacuator units) based on the procedure being performed;
- using a smoke evacuator with a 0.1 µm filter (eg, ULPA filter) or a medical-surgical vacuum system with a 0.1 µm in-line filter in place between the suction wall connection and the suction canister to evacuate small amounts of surgical smoke;
- positioning the smoke capture device (eg, wand, tubing) as close to the surgical site as necessary to effectively collect surgical smoke;
- activating the smoke evacuator at all times when surgical smoke is produced during surgical procedures;
- using a smoke evacuation system during minimally invasive procedures;
- handling used smoke evacuator filters, tubing, and wands as potentially infectious waste by using standard precautions and disposing of these items as biohazardous waste;
- wearing respiratory protective equipment as secondary protection against residual surgical smoke;
- wearing a fit-tested surgical N95 filtering face piece respirator during higher-risk, aerosol-generating procedures and procedures on patients with known or suspected aerosol transmissible diseases (eg, tuberculosis, varicella, rubeola);
- knowing the criteria (eg, procedure type) for use of a suction tubing with an in-line filter to evacuate a small amount of surgical smoke and the indications to convert to using a smoke evacuator with larger tubing and suction capacity; and
- meeting education and competency verification requirements.

[5: Benefits Balanced with Harms]

IV.b. The policy should include procedures for reporting instances of health symptoms and effects associated with surgical smoke exposure (eg, reporting to the occupational health department). *[3: Moderate Evidence]*

The potential hazards of surgical smoke exposure to the perioperative team are respiratory, biologic (eg, blood, virus, bacteria), carcinogenic, chemical, cytotoxic, and mutagenic. Repeated exposure to the contents of surgical smoke increases the possibility of developing adverse effects (See Recommendation II.a.) (Table 4).

TABLE 4. HEALTH EFFECTS OF SURGICAL SMOKE EXPOSURE[1]

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

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From Ulmer BC. The hazards of surgical smoke. AORN J. *2008;87(4): 721-734. Adapted with permission.*

At the request of several health care organizations,[42,53,54,56,64] the Hazard Evaluation and Technical Assistance Branch of NIOSH conducted field investigations of possible health hazards associated with surgical smoke in the workplace. At the Laser Institute at the University of Utah Health Sciences Center in Salt Lake City[64]; Inova Fairfax Hospital in Falls Church, Virginia[53]; Morton Plant Hospital in Dunedin, Florida[54]; and Carolinas Medical Center in Charlotte, North Carolina,[56] NIOSH tested the air for chemicals commonly found in surgical smoke and surveyed employees about heath symptoms associated with surgical smoke exposure. At Inova Fairfax Hospital, Morton Plant Hospital, and the Carolinas Medical Center, formaldehyde, acetaldehyde, and toluene were present in the air. The levels of the compounds were below the relevant criteria for occupational exposure.

Of the employees surveyed at the hospitals, the range of at least one symptom associated with surgical smoke exposure was 36% to 52%. In the hospitals tested, 33% to 46% of the employees described eye and upper respiratory irritation. The National Institute for Occupational Safety and Health recommended that the health care organization's management team implement engineering controls during smoke-producing procedures and that the employees report instances of health symptoms associated with surgical smoke exposure to the organization's occupational health personnel. At the Laser Institute at the University of Utah Health Sciences Center, the investigators found detectable levels of ethanol, isopropanol, anthracene, formaldehyde, cyanide, and airborne mutagenic substances. The National Institute for Occupational Safety and Health recommended the use of smoke evacuators to minimize the potential for health effects and improve visualization of the surgical field.[53,54,56,64]

Ball's[7] research indicated that perioperative nurses report having twice the incidence of some respiratory problems compared to the general population.

Recommendation V

Perioperative personnel should participate in a variety of quality assurance and performance improvement activities that are consistent with the health care organization's plan to improve understanding and compliance with the principles and processes of surgical smoke evacuation.

Quality assurance and performance improvement programs assist in evaluating and improving the quality of patient care and workplace safety and in formulating plans for corrective action. These programs provide data that may be used to determine whether an organization is within its benchmark goals and, if not, to identify areas that may require corrective action.

V.a. The quality assurance and performance improvement program for surgical smoke safety should include assessment of compliance with surgical smoke evacuation. Compliance indicators include

- surgical smoke is evacuated with a smoke evacuator, a laparoscopic filter, or suction with an in-line filter during all smoke-generating procedures;
- the smoke evacuation capture device is positioned as close as possible to the generation of surgical smoke to effectively collect all traces of the smoke;
- an additional standard suction is used to evacuate fluid;
- smoke evacuation filters are used according to manufacturer's instructions for use (eg, single use, all day);
- perioperative team members wear PPE (eg, gloves) when disposing of contaminated filters and smoke supplies; and
- perioperative team members adhere to policies and procedures for smoke evacuation.

[3: Moderate Evidence]

The evidence indicates there is a lack of compliance with surgical smoke evacuation.[8,32-34,36,37,222] Steege et al[32] conducted a web-based survey of members of professional organizations representing health care occupations in which there is routine contact with selected chemical agents including surgical smoke. Laser surgery and electrosurgery were addressed in separate submodules of the survey. Eligible respondents (N = 4,533) worked within 5 ft of surgical smoke generation during electrosurgery (99%) or laser surgery (31%). The respondents were nurse anesthetists (33%), perioperative nurses (19%), anesthesiologists (21%), surgical technologists (16%), and others (11%). Only 47% of the respondents reported always using local exhaust ventilation during laser procedures and 14% reported always using local exhaust ventilation during electrosurgery. Reasons reported for not using local exhaust ventilation included that it was not provided by the employer, the smoke exposure was minimal, and use of local exhaust ventilation was not part of the facility's protocol. Respondents also wrote in answers in the "other" category, and the majority responded that they did not know why local exhaust ventilation was not used and that they had no control over the decision to use local exhaust ventilation. The authors concluded that the decision to use local exhaust ventilation should not be made at the discretion of an individual practitioner when others (eg, anesthesia personnel, nurses) will be exposed to surgical smoke. The survey results provide a valuable snapshot of existing practices and can be used to raise awareness of surgical smoke controls.

V.a.1. Smoke evacuation practices should be measured by direct observation. Other measures to evaluate smoke evacuation practices may include product usage or documentation of smoke evacuation in the perioperative patient record. *[5: Benefits Balanced with Harms]*

V.b. Barriers to evacuating surgical smoke in the perioperative setting should be identified and addressed through interventions to improve smoke safety practices. *[3: Moderate Evidence]*

Barriers include

- no smoke evacuator available,[223]
- smoke accessories (eg, tubing, laparoscopic filter) not available,
- surgeon refusal to evacuate surgical smoke,[223]
- the smoke evacuator being too noisy,[223]
- the smoke evacuator tubing being too cumbersome,[223]
- evacuation of surgical smoke interfering with the procedure, and
- competency deficits (eg, equipment, use).

Identifying barriers to smoke safety practices allows the health care organization to develop relevant interventions to improve surgical smoke evacuation.

Glossary

Aldehydes: Organic compounds containing the CHO radical. Examples are acetaldehyde and formaldehyde.

Aromatic hydrocarbon: Any of a class of hydrocarbon molecules that have multiple carbon rings and that include carcinogenic substances and environmental pollutants.

Hydrogen cyanide: A poisonous, usually gaseous compound, also known as hydrocyanic acid (HCN), that has the odor of bitter almonds and boils at 25.6° C (78.1° F).

Inorganic gases: Gases that do not contain carbon and hydrogen as the principle elements (eg, carbon monoxide, carbon dioxide, sulphur dioxide, nitrous oxide, nitrogen dioxide).

Laser-generated airborne contaminants: Particles, toxins, and steam produced by vaporization of target tissues.

Lung-damaging dust: Categorization of particles smaller than 5 µm that can penetrate to the deepest areas of the lung and obstruct gas exchange.

Nitrile: An organic compound containing a cyanide group —CN bound to an alkyl group.

Smoke: The visible vapor and gases given off by a burning or smoldering substance, especially of organic origin, made visible by the presence of small particles of carbon.

Surgical smoke: The gaseous products of burning organic material created as a result of the destruction of tissue by lasers, electrosurgical units, ultrasonic devices, power instruments, and other heat-producing surgical tools. Surgical smoke can contain toxic gases and vapors such as benzene, hydrogen cyanide, formaldehyde, 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.

Ultra low particulate air (ULPA) filter: Theoretically, an ULPA filter can remove from the air 99.9999% of bacteria, dust, pollen, mold, and particles with a size of 120 nm or larger.

Volatile organic compounds: Carbon-based chemicals that evaporate easily.

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