GEORGIA STATE SENATE
SENATE RESEARCH OFFICE

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ELIZABETH HOLCOMB
DIRECTOR

FINAL REPORT OF THE SENATE STUDY COMMITTEE ON SURGICAL SMOKE EVACUATION SYSTEMS (SR 981)

Committee Members

Senator Gloria Butler
Chair
District 55

Senator Marty Harbin
District 16

Senator Chuck Hufstetler
District 52

Senator Nan Orrock
District 36

Senator Sheikh Rahman
District 5

Prepared by the Senate Research Office, 2020

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STUDY COMMITTEE CREATION, FOCUS, AND DUTIES

The Senate Study Committee on Surgical Smoke Evacuation Systems (the "Study Committee") was created with the adoption of Senate Resolution 981 during the 2020 Legislative Session of the Georgia General Assembly.[1] The Study Committee was charged with studying the efficacy and cost of surgical smoke evacuation systems in surgery rooms. The Resolution noted that gaseous by-product produced from the interaction of tools and heat-producing equipment used during surgical or invasive procedures contains infectious bacteria, viruses, and chemicals.

Senator Gloria Butler of the 55th served as Chair of the Study Committee. The other legislative members were Senator Marty Harbin of the 16th, Senator Chuck Hufstetler of the 52nd, Senator Nan Orrock of the 36th, and Senator Sheikh Rahman of the 5th. The Study Committee met four times at the State Capitol and heard from a variety of interested parties and individuals.

The following legislative staff members were assigned to the Study Committee: Andrew Allison, Senate Press Office; James Beal, Senate Research Office; Kessarin Horvath, Senate Press Office; LaTonia Long, Office of Senator Gloria Butler; and Vince Wiegand, Office of Legislative Counsel.

[1] *See* SR 981. Available at http://www.legis.ga.gov/Legislation/20192020/194983.pdf.

BACKGROUND

The Occupational Safety & Health Administration ("OSHA") within the United States Department of Labor recognizes that hazards exists for perioperative medical staff in the operating room.[2] Medical staff including surgeons, nurses, anesthesiologists, and surgical technologists are exposed to waste anesthetic gases, bloodborne pathogens, smoke plumes, laser and equipment hazards, radiation, and a wide variety of other hazards while providing medical care to patients. Hospitals and ambulatory surgical centers ("ASCs") currently have in place methods and systems for reducing or mitigating hazardous conditions within operating rooms; however, academic studies suggest there are ways to further ensure safe environments for both medical staff and patients.

Health care settings are heavily regulated from a variety of sources. In addition to state physical plant requirements for the buildings and operating rooms themselves, the Georgia Department of Community Health, OSHA, insurance companies, state and federal health spending programs, accreditation groups such as the Joint Commission, and common law standards and duties of care all dictate in some manner the operation of the health care industry. Additionally, there are contractual obligations between medical personnel groups and the hospitals or ASCs in which these groups hold operating privileges. The Study Committee recognizes, and groups that presented during the Study Committee's meetings stated, that authority to make decisions within the operating room generally belongs to surgeons. The chief group advocating for mandating the use of surgical smoke evacuation devices, the Association of periOperative Nurses ("AORN"), indicated their willingness to work with medical facilities outside of legislatively mandating smoke evacuation systems but reported that no progress has been made on the specific issue of removing surgical smoke through the use of smoke evacuation systems.

Over the years, the Centers for Disease Control & Prevention ("CDC") has released studies showing the toxicity and hazards of surgical smoke. OSHA has developed standards for the evacuation of smoke through ventilation systems. In recent years, there have been calls from some perioperative staff to bring targeted smoke evacuation systems into the operating room to use directly next to, or in conjunction with, the tools surgeons use on the patient.

Colorado[3] and Rhode Island[4] have enacted laws requiring hospitals and ASCs to implement policies that prevent human exposure to surgical smoke through the use of a surgical smoke evacuation system during planned surgical procedures that are likely to generate surgical smoke. During the 2020 Legislative Session, Senator Gloria Butler of the 55th introduced Senate Bill 347 which would require hospitals and ASCs operating in this state to adopt policies preventing human exposure to surgical smoke through the use of a surgical smoke evacuation system.[5] While the bill did not reach final passage, it is the impetus for the Study Committee's creation and review of surgical smoke. As the Chair stated during the first meeting, the goal of the Study Committee is to "promote the best long-term health and safety options for all Georgians."

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[2] *Hospital Investigations: Health Hazards*, OSHA Technical Manual, Sec. VI: Ch. 1. Available at https://www.osha.gov/dts/osta/otm/otm_vi/otm_vi_1.html.
[3] Colo. Rev. Stat. Ann. § 25-3-120 (West).
[4] 23 R.I. Gen. Laws Ann. § 23-17-49.1 (West).
[5] *See* SB 347. Available at http://www.legis.ga.gov/Legislation/20192020/189143.pdf.

SUMMARY OF TESTIMONY AND DISCUSSION

Meeting One – September 15, 2020

The Study Committee's first meeting was held at the State Capitol. The purpose of this first meeting was for the Study Committee to broadly understand the issue of surgical smoke. Surgical smoke is the gaseous by-product produced when tissue is dissected or cauterized by heat generating devices such as lasers, electrosurgical units, ultrasonic devices, high speed burrs, drills, and saws.[6] The CDC reports that surgical smoke may contain toxic gases, vapors and particulates, viable and non-viable cellular material, viruses, and bacteria. Furthermore, surgical smoke can transmit human papillomavirus ("HPV") and acute health effects include eye, nose, and throat irritation; headache; cough; nasal congestion; and asthma. Over half a million healthcare workers including surgeons, nurses, surgical technologists, and others are exposed to surgical smoke each year.

According to a CDC survey of healthcare employers' use of local exhaust ventilation ("LEV") nationally, 47 percent of respondents report using LEV during laser surgery and 14 percent report using LEV during electrosurgery. One in three respondents report that LEV is not part of their protocol. The CDC recommends that employees use LEV for all procedures where surgical smoke is generated.[7]

The Chair called on the following individuals to provide testimony:

- **Ms. Brenda Ulmer**, AORN; and
- **Dr. Doreen Wagner**, AORN.

Brenda Ulmer, a registered nurse, perioperative nurse educator, and longtime member of AORN, provided an overview of surgical smoke and personal stories concerning her work in the operating room. Her testimony indicated that, at its most basic definition, surgical smoke is created from the vaporization of human tissue. Cautery and other surgical procedures lead to gaseous by-product containing harmful matter, with electrosurgery procedures creating the most smoke. Electrosurgery units have been used longer than laser tools, but both procedures create smoke containing the same harmful matter. Ms. Ulmer's testimony informed the Study Committee that smoke evacuators were used from the first use of laser tools, but electrosurgery seemingly does not require smoke evacuation. The thinking was that the tools used in electrosurgery—a pencil or "Bovie pen"—created so much heat that harmful matter was sterilized in the course of the procedure. This has since been disproven, according to Ms. Ulmer, and smoke generated from surgical procedures contains as much harmful matter to a human as smoking 27 to 30 cigarettes a day.

Doreen Wagner, a registered nurse, professor with a PhD, researcher, and member of AORN, provided an overview of studies conducted to review the affects surgical smoke has on air quality in the operating room as well as hazards of smoke based on its size in particulate matter ("PM"). The smaller the PM, the greater the chance such PM reaches deeper into lung tissue. This leads to an increased risk of COPD, lung and heart disease, and stroke. Dr.

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[6] Yi Liu, Yizuo Song, Xiaoli Hu, Linzhi Yan, Xueqiong Zhu, Awareness of surgical smoke hazards and enhancement of surgical smoke prevention among the gynecologists, 10 J. Cancer 12 2788 (2019). Appendix VII.

[7] Full CDC/NIOSH report on surgical smoke available at https://www.cdc.gov/niosh/topics/healthcarehsps/smoke.html.

Wagner's testimony indicated that 40 years of studies of air quality show that surgical smoke contains live cells to include bacteria and viruses that can mutate within the human body.

Researchers Katoch and Mysore, based on a study conducted in India, reported in the Journal of Cutaneous and Aesthetic Surgery that surgical smoke is comparable in harm to chronic second-hand smoking.[8] Even when surgical smoke represents only five percent PM and 95 percent water, it poses a significant risk for respiratory tract irritation and mutation, as well as becoming a vector for infectious particles. About 77 percent of PM within surgical smoke is less than 1.1 μm (micrometers). Smoke from electrosurgical procedures is generally less than 0.1 μm in diameter, while smoke produced from laser is around 0.3 μm. Infectious disease and bacteria threats in these particles include HPV, HIV proviral DNA, Staphylococcus, Corynebacterium, and Neisseria.

In response to a question from Senator Rahman of the 5th concerning disposal of smoke, Ms. Ulmer explained the filtration process typically involved in operating room ventilation systems. She explained there is a triple filter involved, and that both charcoal filters and HEPA are available for use. Once the chosen filter has been fully utilized, it is thrown away. Katoch and Mysore report that filtration comes in three forms: 1. Charcoal filter; 2. HEPA; and 3. Ultra low particulate air ("ULPA"). The article advises that a combination of charcoal filter and ULPA are the best methods for filtration as together they remove noxious odors and toxic gases (charcoal), as well as ultrafine PM (ULPA). It is understood that hospitals and ASCs already employ ventilation systems in their operating rooms.

There was significant concern shared by the Study Committee regarding the claim that female perioperative staff suffer spontaneous abortions and complications in pregnancy as a result of surgical smoke. A review conducted by Anderson and Goldman published in JAMA Surgery in 2020 found that female surgeons in the United States experience higher rates of adverse pregnancy outcomes and infertility when compared to the general population.[9] The review cites exposure to radiation, demanding work conditions, anesthetic gases, and surgical smoke as among the many potential sources for complications; however, the authors point out that they found no studies specifically examining the effects of surgical smoke on reproductive outcomes. Anderson and Goldman state that 14 percent of operating room workers use smoke evacuators.

Meeting Two – October 20, 2020

The Study Committee's second meeting was held at the State Capitol. Representatives of the Georgia Hospital Association ("GHA") addressed the Study Committee. The Study Committee also heard from registered nurses and surgeons chosen by AORN to share personal stories related to surgical smoke and its dangers.

The Chair called on the following individuals to provide testimony or submit their stories:

- **Ms. Amy Krieg**, GHA;
- **Ms. Mary Ogg**, AORN;
- **Ms. Vangie Dennis**, AORN;

[8] Saloni Katoch & Venkataram Mysore, Surgical Smoke in Dermatology: Its Hazards and Management, 12 J. Cutaneous and Aesthetic Surg. 1 (2019). Appendix V.

[9] Matlida Anderson & Rose H. Goldman, Occupational Reproductive Hazards for Female Surgeons in the Operating Room, 155 JAMA Surg. 243 (2020). Appendix VI.

- **Ms. Angela Hohn**, personal story;
- **Dr. Doreen Wagner**, PhD, AORN, personal story;
- **Ms. Pat Thornton**, personal story;
- **Mr. Bobby Evans**, personal story;
- **Ms. Tram Clark**, personal story;
- **Ms. Wendy Winer**, personal story;
- **Dr. David Harvey**, personal story; and
- **Dr. Anthony Hedley**, personal story.

Ms. Amy Krieg, on behalf of GHA which represents 160 hospital members in Georgia, provided testimony regarding current regulations and standards that their members follow. Currently, there are four standards that hospitals follow: 1. General duty with reasonable protections against known hazards; 2. Personal protective equipment ("PPE") standards; 3. Respiratory protection programs; and 4. Air contaminant standards. Ms. Krieg reported that OSHA has broad authority when it comes to regulating workplace hazards in hospitals, and that their members follow all OSHA regulations. PPE standards include masks, while respiratory and air contaminant standards include filtration equipment.

Ms. Mary Ogg, a registered nurse and senior perioperative practice specialist, presented on the shortcomings of PPE and HVAC systems for protecting surgical staff from surgical smoke. OSHA requires both PPE and HVAC. Carbon monoxide, among other toxic gases, are present in surgical smoke. She testified that around 50 percent of operating room staff know the dangers of surgical smoke, and that AORN works to educate staff. Surgeon groups are moving towards recommending surgical smoke evacuation systems.

Ms. Vangie Dennis, an AORN member, went over the risks inherent with surgical smoke being present in the operating room. These include both health risks and lessened visibility in the operating room for staff. In her presentation, Ms. Dennis also spoke about Joint Commission standards. The Joint Commission is a non-profit accreditation and certification group that reviews health care facilities for adherence to best practices and requirements for participation in government health care programs. While not directly affiliated with the government, loss of Joint Commission accreditation places health care facilities in jeopardy of losing participation in government health care programs such as Medicare and Medicaid. She indicated that Joint Commission standard EC.02.02.01 provides that smoke evacuation systems "should" be implemented in the operating room, citing only a portion of the standard's language that defines what constitutes "hazardous gases." The full text of the standard provides:

> The hospital minimizes risks associated with selecting, handling, storing, transporting, using, and disposing of hazardous gases and vapors. Note: Hazardous gases and vapors include, but are not limited to, ethylene oxide and nitrous oxide gases; vapors generated by glutaraldehyde; cauterizing equipment, such as lasers; waste anesthetic gas disposal (WAGD); and laboratory rooftop exhaust. (For full text, refer to NFPA 99-2012: 9.3.8; 9.3.9).[10]

[10] *See* Environment of Care (EC) and Life Safety (LS) Chapter Revisions for the Life Safety Code Update, The Joint Commission 6 (Oct. 31, 2016). Available at https://www.jointcommission.org/-/media/deprecated-unorganized/imported-assets/tjc/system-folders/topics-library/prepub_lifesafetycode_disposition_hap_v2pdf.pdf.

The NFPA as cited in the Joint Commission standard is the National Fire Protection Association which provides technical requirements for dealing with waste gas and "medical plume evacuation" using various methods including LEV.

Additionally, this meeting received several personal stories from medical staff who have experience in operating rooms where surgical smoke is present. Summaries of these personal stories are below.

- Ms. Angela Hohn, a registered nurse, was diagnosed with Stage IV lung cancer in 2020 which her primary care physician attributes to her exposure to surgical smoke. Until her diagnosis, she had been a perioperative nurse since 1979.
- Dr. Doreen Wagner, who also presented at the first meeting, told the story of her pregnancy and birth. Her concern was that her daughter's first breath was of hazardous tissue in the operating room as a result of an emergency C-section.
- Ms. Pat Thornton, a registered nurse, explained that the smell of burnt tissue and toxins in the air of the operating room led to nosebleeds and hypertension. She worked in the operating room for 19 years.
- Mr. Bobby Evans, a surgical technician, explained his increased sensitivity to bad air quality. He has worked as a surgical technician for one year.
- Ms. Tram Clark, an operating room nurse, shared her story of burning sensations in her eyes during surgical procedures in the operating room. She blames repetitive exposure to irritants from surgical smoke as the reason for needing eye care. She also shared her concerns for patients.
- Ms. Wendy Winer, a registered nurse, reports that nurses and technicians who complain become victims of intimidation by hospital administrators. She specifically refuses to work in any operating room that does not have a smoke evacuation system in use. She has worked as a nurse for 40 years. This was a pre-recorded video.
- Dr. David Harvey, a medical doctor and surgical dermatologist, shared data regarding surgical smoke with the Study Committee. This was a pre-recorded video.
- Dr. Anthony Hedley, an orthopedic surgeon from Phoenix, Arizona, shared his story of undergoing a double lung transplant as a result of complications from surgical smoke exposure. This was a pre-recorded video.

The Study Committee shared concerns regarding equipment currently in use. Masks are only effective to a degree and not totally effective against finer PM. There was also concerns that nursing staff face retaliation from hospital administrators should they report problems. GHA stated there are multiple layers of protections within and without hospitals for staff to lodge complaints concerning hazardous work environments. These include direct supervisors, OSHA investigators, and GHA itself, all of which require protections for complainants.

Senator Orrock of the 36th stated that the problem of surgical smoke should be of a national concern and encouraged AORN and GHA, as well as other stakeholders to have conversations and work towards solutions outside of legislative mandates. AORN indicated its willingness to work with hospitals and administrators towards solutions. Ms. Dennis stated that surgeon groups are moving towards recommending surgical smoke evacuation systems.

Meeting Three – November 17, 2020

The Study Committee's third meeting was held at the State Capitol. The purpose of this meeting was for the Study Committee to hear how to best protect patients and personnel in

the operating room. The Study Committee also heard from an Emory Hospital physician-administrator regarding their current understanding of surgical smoke and related dangers.

The Chair called on the following individuals to provide testimony or submit their stories:

- **Mr. Richard Lamphier**, Georgia Nursing Association ("GNA");
- **Ms. T.C. Parker**, Association of Surgical Technologists ("AST");
- **Dr. Jyotirmay Sharma**, Emory Hospital, not on behalf of;
- **Ms. Vangie Dennis**, AORN;
- **Dr. Andrea Steege**, PhD, CDC/National Institute for Occupational Safety and Health ("NIOSH"), not on behalf of;
- **Mr. Christopher Hudgins**, AORN;
- **Ms. Jennifer Pennock**, AORN;
- **Dr. David Harvey**, personal story;
- **Dr. Caleb Nelson**, personal story; and
- **Dr. Daniel Broderick**, personal story.

Mr. Richard Lamphier's testimony, on behalf of GNA, noted that Georgia is the fourth worst state in the United States in terms of a nursing shortages. According to NurseJournal.org, Georgia is fifth worst in the United States with 10.23 nurses per 1,000 population. The average in the United States is 12.06 nurses per 1,000 population. Georgia ranks ahead of Texas, California, Nevada, and South Carolina.[11] Becker's Hospital Review forecasts that Georgia will have the seventh worst nursing shortage in the U.S. by 2025.[12] GNA supports AORN's position that legislation mandating smoke evacuation systems is required.

Ms. T.C. Parker, on behalf of AST, testified as to her group's support of AORN's position that legislation is required to mandate smoke evacuation systems.

Dr. Jyotirmay Sharma, medical doctor and chief quality officer with Emory Hospital's Department of Surgery, testified as to Emory's current policies and practices. There was no indication he was speaking on behalf of Emory. He indicated he has reviewed material regarding surgical smoke and found that implementing the desired smoke evacuation system would hinder a surgeon's abilities and vision. He indicated that masks are proven to mitigate the harmful effects of surgical smoke while implementing direct surgical smoke evacuation equipment in the operating room could lead to underutilization of masks. His hospital has in place equipment for evacuating smoke, but it is an adjunct to proven methods. Air exchanges within operating rooms already exchange 98 percent of the air within 15 minutes. It is Dr. Sharma's position that data is lacking to necessitate changing current protocols.

Ms. Vangie Dennis, on behalf of AORN, testified as to the costs of implementing a smoke evacuation system. Dennis' testimony gave an example of costs associated with smoke evacuation pens, wands, and disposable devices such as filters. Her calculated costs for the least expensive inline filter option are $1.97 per operating room per day. A smoke evacuator plus tubing was calculated at $10.25 per day, with a smoke evacuator costing $2,000.00. An

[11] *U.S. Nurse-to-State Population Ratio*, NurseJournal (2020). Available at https://nursejournal.org/community/the-us-nursing-shortage-state-by-state-breakdown/.

[12] *Which states will have the biggest nursing shortages by 2025?*, Becker's Hospital Review (Feb. 13, 2017). Available at https://www.beckershospitalreview.com/hr/which-states-will-have-the-biggest-nursing-shortages-by-2025.html.

inline filter plus smoke pencil costs $13.97 per day. Evacuation in laparoscopic procedures was estimated at $11.97 per day, accounting for a laparoscopic filter.

Dr. Andrea Steege, a research epidemiologist with NIOSH which is part of the CDC, testified as to her findings while employed by the federal government. She did not testify on behalf of the CDC, NIOSH, or any governmental agency. Dr. Steege's paper was published in 2016 in the American Journal of Industrial Medicine and funded by NIOSH. Her findings were that LEV is used in 14 percent of electrosurgery procedures and in 47 percent of laser surgery procedures nationally.[13] Her findings were based on surveys sent to members of professional practice organizations. Other noteworthy findings in Dr. Steege's paper:

- 49 percent of laser surgery respondents and 44 percent of electrosurgery respondents reported never having been trained on the hazards of surgical smoke;
- Of those reporting the availability of LEV in their operating rooms, portable smoke evacuators and room wall suction exhaust ventilation systems were equally used in laser surgery procedures, while wall suction systems were favored for electrosurgery procedures;
- Most respondents reported never wearing a respirator (N95 or air-purifying respirator);
- 29 percent of laser surgery respondents and 58 percent of electrosurgery respondents reported never using either LEV or respirators;
- Laser and surgical mask use were common, 90 percent and 98 percent use, respectively;
- During laser surgery, 20 percent of respondents reported using LEV and another 20 percent reported "use of a different system to remove smoke";
- During electrosurgery, 36 percent reported using a different system to remove the smoke, with the top two reasons for not using LEV was reported as "not part of our protocol" and "not provided by employer"; and
- Seven percent of laser surgery respondents and 12 percent of electrosurgery respondents reported surgeons' choice to not use LEV was the reason for not doing so.

Dr. Steege's recommendation is for health care facilities to develop standard operating procedures which stipulate to the use of LEV in all procedures where surgical smoke is generated.

Mr. Christopher Hudgins, a registered nurse, member of AORN, and member of the legislative committee of the Georgia Council of Perioperative Registered Nurses, testified as to his group's efforts to bring awareness to the issue and options for respiratory protection. These options are procedural masks, elastomeric respirators, powered air purifying respirators, surgical masks, and filtering facepiece respirators. His conclusion was that none of the mask options are sufficient for protecting the operating room worker.

Ms. Jennifer Pennock, government affairs for AORN, provided testimony as to the legislative successes AORN has had in other states. Colorado and Rhode Island enacted legislation, with nine other states—including Georgia—having filed legislation in the past.

[13] Andrea L. Steege, James M. Boiano, and Marie H. Sweeney, Secondhand smoke in the operating room? Precautionary practices lacking for surgical smoke, 59 Am. J. Ind. Med. 1020-1031 (Nov. 2016). Appendix II.

Additionally, this meeting received personal stories from medical staff who have experience in operating rooms where surgical smoke is present. Summaries of these personal stories are below.

- Dr. David Harvey, a medical doctor and surgical dermatologist, shared a personal story at a previous meeting. He restated much of what the Study Committee has heard previously concerning bacteria present in surgical smoke.
- Dr. Caleb Nelson, a medical doctor and pediatric urologist with Boston Children's Hospital, expressed his support for legislation to require smoke evacuation systems.
- Dr. Daniel Broderick, a medical doctor with Atlanta Medical Center's anesthesiology department, explained his operating room's procedures for protecting staff from COVID-19.

There was significant disagreement between members of AORN and Dr. Sharma as to the best ways to mitigate or eliminate surgical smoke. Senator Orrock of the 36th pointed out that government-funded studies through NIOSH and guidelines issued by various organizations point to evacuation as being the most recommended form of mitigation or elimination. Dr. Sharma disputed the findings of Dr. Steege's NIOSH article, stating it was unknown as to whether smoke evacuation systems removed the specific harm created in operating rooms.

Meeting Four – December 16, 2020

The Study Committee met for a fourth and final time in order for the members to vote on this Final Report. This Final Report was adopted.

RECOMMENDATION

1. The Study Committee finds that surgical smoke represents a hazard to the health of operating room staff and patients. Current guidelines lack the legal force necessary to bring about the positive change needed for the health and safety of Georgians. It is the recommendation of the Study Committee that legislation be enacted in 2021 to require hospitals and ASCs to adopt policies providing for the evacuation of surgical smoke from their facilities.

Respectfully submitted,

FINAL REPORT OF THE SENATE STUDY COMMITTEE ON SURGICAL SMOKE EVACUATION SYSTEMS

Senator Gloria Butler
Chair
District 55

APPENDICES

Appendix I -- *Overview of Surgical Smoke Memorandum*, Senate Research Office.

Appendix II -- Steege, Boiano & Sweeney, Secondhand smoke in the operating room? Precautionary practices lacking for surgical smoke, CDC/NIOSH.

Appendix III -- *Methods of Protection & Cost of Service*, PowerPoint, AORN.

Appendix IV -- *Respiratory Protection Health Care Workers*, PowerPoint, AORN.

Appendix V -- Katoch & Mysore, Surgical Smoke in Dermatology: Its Hazards and Management, Journal of Cutaneous and Aesthetic Surgery.

Appendix VI -- Anderson & Goldman, Occupational Reproductive Hazards for Female Surgeons in the Operating Room, JAMA Surgery.

Appendix VII -- Liu, Song, Hu, Yan & Zhu, Awareness of surgical smoke hazards and enhancement of surgical smoke prevention among the gynecologists, Journal of Cancer.

GEORGIA STATE SENATE
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ELIZABETH HOLCOMB
DIRECTOR

MEMORANDUM

Date: September 8, 2020

To: Members of the Study Committee on Surgical Smoke Evacuation Systems

From: James Beal

Re: Overview of Surgical Smoke

The following provides an overview of surgical smoke, its origins, the risks associated with inhaling surgical smoke, and Senate Bill 347. If you have any questions, please contact James Beal with the Senate Research Office at james.beal@senate.ga.gov.

Surgical smoke is the gaseous by-product produced when tissue is dissected or cauterized by heat generating devices such as lasers, electrosurgical units, ultrasonic devices, high speed burrs, drills, and saws.[1] The Centers for Disease Control and Prevention ("CDC") reports that surgical smoke may contain toxic gases, vapors and particulates, viable and non-viable cellular material, viruses, and bacteria. Furthermore, surgical smoke can transmit human papillomavirus ("HPV") and acute health effects include eye, nose, and throat irritation; headache; cough; nasal congestion; and asthma. Over half a million healthcare workers including surgeons, nurses, surgical technologists, and others are exposed to surgical smoke each year.

According to a CDC survey of healthcare employers' use of local exhaust ventilation ("LEV"), 47 percent of respondents report using LEV during laser surgery and 14 percent report using LEV during electrosurgery. One in three respondents report that LEV is not part of their protocol. The CDC recommends that employees use LEV for all procedures where surgical smoke is generated.[2]

Senate Bill 347

In 2020, Senate Bill 347 was introduced to require hospitals and ambulatory surgical centers to adopt policies for evacuating surgical smoke during surgical or invasive procedures. The bill requires that these policies must provide for the use of a surgical smoke evacuation system, which the bill defines as equipment designed to capture and neutralize surgical smoke at the point of origin. The bill did not make it out of the Committee on Health & Human Services before the end of the 2020 Session.

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[1] Yi Liu, Yizuo Song, Xiaoli Hu, Linzhi Yan, Xueqiong Zhu, Awareness of surgical smoke hazards and enhancement of surgical smoke prevention among the gynecologists, 10 J. Cancer 12 2788 (2019).
[2] Full CDC report and findings on surgical smoke available at https://www.cdc.gov/niosh/topics/healthcarehsps/smoke.html.

APPENDIX I

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Secondhand Smoke in the Operating Room? Precautionary Practices Lacking for Surgical Smoke

Andrea L. Steege, PhD, MPH*, **James M. Boiano, MS, CIH**, and **Marie H. Sweeney, PhD, MPH**
Division of Surveillance, Hazard Evaluations and Field Studies, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Cincinnati, Ohio

Abstract

Background—Consensus organizations, government bodies, and healthcare organization guidelines recommend that surgical smoke be evacuated at the source by local exhaust ventilation (LEV) (i.e., smoke evacuators or wall suctions with inline filters).

Methods—Data are from NIOSH's Health and Safety Practices Survey of Healthcare Workers module on precautionary practices for surgical smoke.

Results—Four thousand five hundred thirty-three survey respondents reported exposure to surgical smoke: 4,500 during electrosurgery; 1,392 during laser surgery procedures. Respondents were mainly nurses (56%) and anesthesiologists (21%). Only 14% of those exposed during electrosurgery reported LEV was always used during these procedures, while 47% reported use during laser surgery. Those reporting LEV was always used were also more likely to report training and employer standard procedures addressing the hazards of surgical smoke. Few respondents reported use of respiratory protection.

*Correspondence to: Andrea L. Steege, PhD, MPH, CDC, National Institute for Occupational Safety and Health, Division of Surveillance, Hazard Evaluations and Field Studies, 1090 Tusculum Ave, MS R-18, Cincinnati, OH 45226-1998. asteege@cdc.gov.

AUTHORS' CONTRIBUTIONS
ALS contributed to the design of the survey, interpreted data, performed statistical analysis, drafted and revised the manuscript, and is responsible for all aspects of the work. JMB conceived of and contributed to the design of the study, interpreted the data and helped draft and revise the manuscript. MHS contributed to the design of the survey, interpreted the data, and helped revise the manuscript. All authors approved of the final version of the manuscript.

ETHICS APPROVAL AND INFORMED CONSENT
The NIOSH Human Subjects Review Board determined that the activities in this project were surveillance and did not meet the criteria of research according to 45 CFR 46.1101(b) (2) and CDC Guidelines for Defining Public Health Research and Public Health Non-Research. This was an anonymous, web-based survey.

DISCLOSURE (AUTHORS)
The authors declare no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD
Steven Markowitz declares that he has no conflicts of interest in the review and publication decision regarding this article.

DISCLAIMER
The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health. This article is not subject to U.S. copyright law.

Work for this manuscript was performed at the NIOSH Alice Hamilton Laboratory, Cincinnati OH.

SUPPORTING INFORMATION
Additional supporting information may be found in the online version of this article at the publisher's web-site.

APPENDIX II

Conclusions—Study findings can be used to raise awareness of the marginal use of exposure controls and impediments for their use.

Keywords

surgical smoke; local exhaust ventilation (LEV); electrosurgery; smoke evacuators; laser surgery; engineering controls; healthcare workers

INTRODUCTION

Use of lasers or electrosurgical devices during surgical procedures can generate surgical smoke from thermal destruction of tissue. Not only is surgical smoke a nuisance because it has an unpleasant odor and can obstruct the surgeon's view of the surgical site [Ulmer, 2008; Gorman et al., 2013]; but, surgical smoke has been shown to contain a variety of toxic gases, vapors and particulates including carbon monoxide, polyaromatic hydrocarbons, benzene, hydrogen cyanide, formaldehyde, viable and non-viable cellular material, viruses and bacteria [Sawchuk et al., 1989; NIOSH, 1996; Garden et al., 2002; Alp et al., 2006; Ulmer, 2008; Novak and Benson, 2010; Pierce et al., 2011; Gorman et al., 2013; OSHA, 2015]. Transmission of HPV through surgical smoke has been documented [Hallmo and Naess, 1991]. Surgical smoke has been shown to be mutagenic, cytotoxic and genotoxic [Tomita et al., 1981; Gatti et al., 1992; Alp et al., 2006]. The quantity and quality of smoke generated depends on several factors including type of surgical procedure (e.g., laser, electrosurgical, ultrasonic), type and infectious nature of the tissue, extent of surgery (ablation, cutting, or coagulation), power levels used, and duration of the surgical procedure [Alp et al., 2006; Novak and Benson, 2010].

Each year, an estimated 500,000 healthcare workers including surgeons, nurses, anesthesiologists, surgical technologists, and others are exposed to laser or electrosurgical smoke [OSHA, 2015]. Surgical smoke exposures have been linked to acute adverse health effects in exposed healthcare workers, including: eye, nose and throat irritation; headache; cough; nasal congestion; and asthma and asthma-like symptoms [Wilks, 1959; King and McCullough, 2001; Alp et al., 2006; Ulmer, 2008]. Surgical smoke has been shown to induce acute and chronic inflammatory changes (e.g., emphysema, asthma, chronic bronchitis) in the respiratory tract of animal models [Baggish and Elbakry, 1987; Winston, 1994], but data on long-term effects of exposure to surgical smoke are not available.

Several diverse professional, consensus, and governmental organizations recommend local exhaust ventilation (LEV) to protect healthcare workers from the hazard of surgical smoke, including: National Institute for Occupational Safety and Health [NIOSH, 1996]; Association of periOperative Registered Nurses [AORN, 2014a,b]; Association of Surgical Technologists [AST, 2012]; the American Society for Laser Medicine and Surgery Laser Safety Committee [ASLMS, 2007]; the American National Standards Institute ANSI Z136.3-2005 (introduced in 2005, updated in 2011) [ANSI, 2005]; Occupational Safety and Health Administration [OSHA, 2015]; Emergency Care Research Institute [ECRI, 2007]; Ministry of Health, New South Wales, Australia [2015]; and the Canadian Centre for Occupational Health and Safety [2014]. Although some guidelines are specific to laser

surgery, NIOSH, AORN, and ASLMS do not distinguish surgical smoke produced as a result of laser surgery from that produced during electrosurgery. Although OSHA does not currently have a regulatory standard for surgical smoke, a hospital e-tool on protecting workers from various hazards including surgical smoke is available [OSHA, 2015]. Their recommendations, like the others mentioned above, include using engineering controls such as LEV in the form of portable smoke evacuators or room suction systems with inline filters. Engineering controls, including LEV, represent the preferred method in a hierarchical approach to mitigate workplace hazards [Manuele, 2005].

The primary objective of this study was to characterize use of exposure controls, and barriers to using LEV and Personal Protective Equipment (PPE) (including respiratory protection) by healthcare personnel who were exposed to surgical smoke generated by laser or electrosurgical procedures (i.e., electrocautery, diathermy, and procedures using ultrasonic devices). Previous surveys asking about exposure to surgical smoke have primarily been among perioperative nurses [Edwards and Rieman 2008, 2012; Ball, 2010b] with one among surgeons [Spearman et al., 2007]. They found that use of local exhaust ventilation was not universal. Factors influencing their use included increased hazard awareness, positive perceptions concerning the attributes of smoke evacuation guidelines, and leadership support, among others. Impediments to using smoke evacuators included lack of equipment/ repair parts, physician resistance, uncertainty about health hazards, cost, noise, and staff complacency [Spearman et al., 2007; Edwards and Rieman, 2008, 2012; Ball, 2010b]. This survey provides the perspective of a diverse sample of healthcare workers including nurse anesthetists, anesthesiologists, surgical technologists and assistants, in addition to perioperative nurses, and their experience with safety precautions in place to provide protection from the toxic components of surgical smoke. We also looked at characteristics that correlate with use of local exhaust ventilation and how they compared to available literature.

METHODS

Survey Methodology

The NIOSH Health and Safety Practices Survey of Healthcare Workers (referred to hereafter as the Survey), an anonymous, multi-module, web-based survey was conducted January 28 through March 29, 2011. The study population primarily included members of professional practice organizations representing healthcare occupations which routinely use or come in contact with selected chemical agents including surgical smoke. Information on overall methods used in the development and testing of the survey instrument, survey design and functionality, survey population, survey implementation, respondent characteristics, and other information including strengths and limitations of the survey have been described elsewhere [Steege et al., 2014].

Survey Instrument

Practices related to control of surgical smoke were asked in a hazard module targeted to healthcare workers who work within 5 feet of a source of surgical smoke. After general questions on years exposed to surgical smoke, training on hazards of surgical smoke, and

workplace procedures that address surgical smoke, respondents were directed to either a submodule on laser surgery, electrical surgery, or each in turn. Laser surgery and electrosurgery were addressed in separate submodules due to differences in previously reported practices and guidelines; each submodule included the same 19 questions. Data on demographics, occupation and employer characteristics were collected through the Survey core module. When answer choices were not exhaustive, the survey allowed participants to check "other" and type in responses in their own words. These were coded to the answers provided in the survey where appropriate or new responses were coded and are reported separately. All of the topic areas included in the surgical smoke module are listed in Supplementary Information Appendix A. It was possible for respondents to complete the surgical smoke module and not the core module. In those cases, demographic information is not available.

Data Analysis

Data were analyzed using SAS 9.3 (Cary NC: SAS Institute, Inc.). Descriptive data, including frequencies and proportions, are presented as well as workplace and employee characteristics stratified by whether LEV is always or sometimes/never used. For the stratified analysis chi-square *P* values (Pearson chi-square for nominal variables; Mantel–Haenszel for ordinal variables) are presented. Although we did not have a priori hypotheses, statistical testing allowed us to compare our results to the existing literature.

Human Subjects Review Board

The NIOSH Human Subjects Review Board (HSRB) determined that the activities in this project were surveillance and did not meet the criteria of research according to 45 CFR 46.1101(b)(2) and CDC Guidelines for Defining Public Health Research and Public Health Non-Research [CDC, 2010]. Informed consent was implied in this anonymous web survey. Although not required by the HSRB, elements of a traditional informed consent document were included in invitation letter, which included a weblink to begin the survey.

RESULTS

There were 4,533 respondents who were eligible and completed the hazard module addressing exposure to surgical smoke. Respondents worked within 5 feet of a source of surgical smoke during electrosurgery (99%) and/or laser surgery (31%). These respondents were predominately female (61%) and white (91%), with the largest proportion in the 41 to 55 year age group (45%). Approximately half had education exceeding a bachelor's degree (53%) (Supplementary Information Appendix B).

Over half of respondents were nurses (56%), including nurse anesthetists (33%), perioperative nurses (19%), and other nursing specialties (19 specific ones) (Table I). In addition, over half of respondents identified themselves as anesthesia care providers, including the nurse anesthetists, physician anesthesiologists (21%), and anesthesiologist assistants (2%). Respondents also included technologists and technicians and surgical assistants. Respondents were fairly evenly distributed in terms of years of experience in their current occupation. Less than 1 in 10 respondents was a labor union member (Table I).

Respondents primarily worked for hospital employers (83%) while less than one in five (17% laser surgery; 16% electrosurgery) worked for ambulatory healthcare service employers (Table I). One-third worked for employers with more than 1,000 employees while approximately one-fourth (25%) worked for employers with less than 100. Most employers were either for-profit or non-profit entities with only 12% in the public sector. Almost 60% of respondents said that their primary place of employment was in a large city with 50,000 people or more. Less than 10% reported that they worked in a rural area.

Reported Exposure to Surgical Smoke During Laser Surgery and Electrosurgery

With regard to exposure during both laser surgery and electrosurgery, more than 4 in 10 respondents reported that they had more than 20 years of experience working in areas where surgical smoke was generated; over 65% had more than 10 years (Table I). Most respondents who were exposed to surgical smoke during laser surgery reported that in the past 7 calendar days they had only been within 5 feet of the source for one day (71%), for less than a total of 1 hr (61%), and involved in one (52%) or two to five procedures (42%). Respondents had more opportunity for exposure during electrosurgery with more than half (57%) reporting that they worked within 5 feet of surgical smoke during electrosurgery four or more days of the past 7. Twenty-two percent of respondents exposed during electrosurgery reported working more than 20 hr within 5 feet of surgical smoke and two-thirds (68%) were present for more than five procedures in the past 7 calendar days.

Worker Training, Employer Procedures, and Exposure Monitoring

In spite of their long term exposure to surgical smoke, 49% of laser surgery respondents and 44% of electrosurgery respondents said that they have never had training on the hazards of surgical smoke and another third were trained more than 12 months ago (Table II). Less than one-third of respondents reported that their employer had procedures for addressing the hazards of surgical smoke during either type of procedure; 4 out of 10 did not know whether their employer had procedures. Most respondents were unaware whether exposure monitoring had been conducted in the past 12 months, regardless of whether they had been around surgical smoke during laser surgery or electrosurgery.

Use of Local Exhaust Ventilation (LEV)

Only half (47%) of respondents reported that LEV was always used during laser surgery while even fewer (14%) reported that LEV was always used during electrosurgery (Table III). Those who were exposed during both electrosurgery and laser surgery were more likely to report LEV is always used during electrosurgery than those who were only exposed during electrosurgery procedures (data not shown). Of those who had LEV available for laser surgery, portable smoke evacuators and room wall suction exhaust ventilation systems were equally used; while for electrosurgery, room wall suction was favored. Thirteen percent of laser surgery respondents and 18% of electrosurgery respondents reported use of both types of systems.

Personal Protective Equipment (PPE)

Most respondents reported never wearing a respirator (N95, half-facepiece air-purifying respirator with particulate filter, or powered air-purifying respirator with particulate filter) (90% for laser surgery, 96% for electrosurgery) (Table III). None of the respondents mentioned N100 respirators in the space for "other" responses. For laser surgery and electrosurgery respectively, 29% and 58% never used either LEV or respirators (data not shown). Only two-thirds (63% laser surgery; 64% electrosurgery) of those who reported wearing a respirator had been fit-tested.

Those who were exposed to surgical smoke during laser surgery were more likely to always wear eye protection (74%). For electrosurgery, only 39% always wore eye protection.

Laser and Surgical Masks

Use of laser and surgical masks was common with 90% of respondents to the laser surgery submodule and 98% of electrosurgery respondents (data not shown).

Reasons Reported for Not Using LEV and PPE

The most frequently reported reasons for not using LEV during laser surgery were that using LEV was "not part of our protocol," "exposure was minimal," and LEV was "not provided by employer" (Table IV). Approximately one-fifth of those exposed to surgical smoke during laser surgery reported that LEV is not used because "general room ventilation is sufficient to dissipate the smoke," while another 20% report that they "use a different system to remove smoke." Respondents to the electrosurgery submodule were more likely to report not using LEV due to a different system being used or sufficient general room ventilation (36% and 29% respectively). "Not part of our protocol," and "not provided by employer," were also top reasons for lack of LEV use during electrosurgery.

A large proportion of respondents chose to enter "other" and type in their own reason. For laser surgery, many people typed in that they did not know why LEV was not used; other respondents wrote that the procedures were internal to the patient (e.g. laparoscopic surgeries) so they were not exposed to surgical smoke. For electrosurgery, the majority of "other" answers were also essentially "I do not know" why LEV was not used but, in addition, a large number did not feel like they had any control over the decision of whether LEV was used or not because of decisions made by other staff (e.g., surgeons, supervisors, perioperative nurses, surgical assistants) or hospital management.

Approximately half of respondents for both laser surgery (48%) and electrosurgery (56%) reported that using respirators was "not part of our protocol." Also reported in order of frequency are: "exposure was minimal," "not provided by employer," and "not readily available in work area." The most common "other" response for not wearing a respirator included that laser masks or standard surgical masks were used. The next most common "other" reason was that respirators were only used when a patient had a known infectious disease (e.g., Mycobacterium tuberculosis, HPV). Knowing the patient did not have various infectious diseases was the most common "other" reason for not wearing a respirator typed in by those exposed to surgical smoke during electrosurgery.

The most common reasons for not wearing protective eyewear were that "exposure was minimal," and using it was "not part of our protocol."

Characteristics of Respondents and Workplaces Where LEV Is Always Used

Proportions of workers reporting that LEV is always used when they are exposed to surgical smoke during laser surgery or electrosurgery by workplace characteristics are presented in Table V. Of respondents exposed to surgical smoke during both laser surgery and electrosurgery, those who received recent training on the hazards of surgical smoke were more likely to report consistent LEV use compared to those who had never received training.

Similarly, for both laser surgery and electrosurgery, those whose employer had standard procedures that addressed the hazards of surgical smoke reported that LEV was more likely to be used than those whose employer did not.

Respondents with ambulatory healthcare services employers were more likely to report always having LEV than those who worked for hospitals for laser surgery (62% vs. 45%, respectively); for electrosurgery both had equally poor access (16% and 14%, respectively). For both laser and electrosurgery, workers in smaller establishments were more likely to report consistent use of LEV. Neither employer ownership type (i.e., for-profit, non-profit or public sector), nor population density where employer is located were significantly associated with consistent LEV use. Of occupations with more than 20 respondents, gastroenterology/endoscopy nurses (19%) and nurse anesthetists (16%) were most likely to report that LEV is always used for electrosurgery. Use of LEV by occupation was not significantly different for laser surgery respondents.

Those who spent less time (fewer days, fewer hours, fewer procedures for both laser surgery and electrosurgery respondents, and fewer years—electrosurgery only) were more likely to work in areas with consistent LEV than those who spent more time around surgical smoke. For laser surgery, those with more than 20 years of experience working around surgical smoke were also more likely to report LEV use.

DISCUSSION

This study represents the largest survey describing precautionary practices around surgical smoke, with over 4,500 respondents. The primary purpose of this study was to describe surgical smoke exposure control precautions used during laser and electrosurgical procedures and to better understand impediments to their use. Perspectives of a diverse group of healthcare workers including nurse anesthetists, physician anesthesiologists, perioperative nurses, surgical technologists as well as other nursing and support personnel are included; previous US surveys have included mainly perioperative nurses [Ball 2010a; Edwards and Rieman 2008, 2012]. Both of these previous surveys had approximately the same ratios of respondents who were hospital-based versus ambulatory center-based as the current survey, with Ball [2010a,b] having a slightly higher proportion being hospital based. Edwards and Reiman [2008] asked about LEV use for both laser as well as electrosurgery, whereas Ball confined her study to practices around electrosurgery.

In spite of numerous guidance documents recommending that LEV be used when surgical smoke is generated [NIOSH, 1996; ANSI, 2005; ASLMS, 2007; Edwards and Reiman, 2008, 2012; AST, 2012; Canadian Centre for Occupational Health and Safety, 2014; AORN, 2014a,b; Ministry of Health, New South Wales, Australia, 2015], our survey found that LEV is not always used to remove surgical smoke at the source. Only half (47%) of respondents who were present during laser surgery reported that any kind of LEV was always used; the proportion where LEV was always used during electrosurgery was even lower (14%). Although the ANSI standard specifically targets laser generated airborne contaminants, it also recommends that LEV should be used to evacuate smoke during electrosurgery [ANSI, 2005].

A U.K. survey in Wessex England on surgical smoke practices in 111 respondents reported approximately 52% of surgeons and 67% of surgeons-in-training used any type of LEV during diathermy procedures (a type of electrosurgery). Wall suction was most common, with some use of laparoscopic smoke extractors/filters [Spearman et al., 2007]. The U.K. investigators also reported that smoke was sometimes cleared by opening laparoscopic portals, presumably directly into the operating theater, and "blowing away smoke," exposing the surgical team to the contaminants of insufflation gas containing surgical smoke. Other published surveys do not report an overall proportion of respondents who report whether LEV was used or not used. In our survey, those who were present for both electrosurgery and laser surgery were more likely to report LEV is always used during electrosurgery—although use is still much lower than for laser surgery—perhaps indicating that habits, training, or procedures used in laser surgery had some influence over those used in electrosurgery.

As Edwards and Reiman [2008] point out, differences in use of LEV for laser surgery versus electosurgery may be due to the fact that the ANSI Z136 standard exists mainly to ensure that users/ancillary personnel are protected from eye and skin injuries from lasers though non-beam hazards such as surgical smoke are also addressed; no such industry consensus document exists for electrosurgery. Some states or localities also require licensure for operating laser devices [ANSI, 2005]. Although AORN's Recommended Practices for Laser Safety in Perioperative Practice Settings and Recommended Practices for Electrosurgery [AORN, 2014a,b] have much of the same language for precautions related to surgical smoke, other recommendations in the laser safety document may contribute to organizations following the recommendations for laser surgery more carefully than for electrosurgery. For laser surgery, AORN and ANSI Z136 recommendations include assembling a laser safety committee, having a laser safety officer, and possibly a laser safety specialist too [ANSI, 2005; AORN, 2014a]. Having an interdisciplinary team responsible for safe use of lasers may ensure greater awareness of all health and safety hazards, including surgical smoke.

For laser surgery the top reasons given for LEV not being used were that it was "not part of our protocol," followed by "exposure was minimal" and "not provided by employer." "Not part of our protocol" and "not provided by employer" were the 2nd and 4th most reported reasons for why LEV was not used for electrosurgery. These reasons indicate that managers are not aware of hazards of surgical smoke or lack commitment to controlling surgical

smoke. This concurs with Ball's [2010a] finding that strong leadership support was a factor in more widespread use of LEV.

The top reason given for why LEV was not used for electrosurgery was that "a different system was being used," and the 3rd was that "general room ventilation was sufficient." The survey did not ask respondents to specify what other system they used although one possibility is a blood suction canister, used to suction blood and other fluids from the surgical site. This would not be appropriate for surgical smoke evacuation which requires specific filters that would lose their effectiveness if contaminated by fluids. General room ventilation is recommended by NIOSH as a supplemental measure to remove smoke but is not appropriate as primary prevention [NIOSH, 1996]. LEV should remove surgical smoke at the source and be within 2 inches to be effective [NIOSH, 1996].

Examining the different characteristics of the healthcare workers and their employers, we found the largest difference in consistent access to LEV between those who had recently received training on the hazards of surgical smoke versus those who had never been trained. Ball [2010a] also found that LEV was more often used by nurses with increased training and knowledge. Ball's finding that strong leadership support was a factor in more widespread use of LEV also may be related to our finding that always using LEV was associated with having facility procedures on how to safely deal with surgical smoke and may be an indicator of leadership support for its use. Unexpectedly, we found that ambulatory healthcare services employers and those with fewer employees were more likely to have LEV for both laser and electrosurgery. For electrosurgery, employer type was not significantly different.

Healthcare workers who reported that they were exposed to surgical smoke during electrosurgery were exposed for a much longer period of time. Over half of respondents who were exposed during electrosurgery were exposed 4 or more days in the past 7 (57%) and >5 hr per week (52%). For laser surgery most respondents were exposed only 1 day (71%) and <6 hr per week (92%) and for far fewer procedures. This is especially concerning because at least one study found smoke from electrosurgery to be more mutagenic than smoke from laser surgery [Tomita et al., 1981]. In addition, we found those respondents who spent more time exposed to surgical smoke were less likely to report that LEV was used.

Ball [2010b] also found that physicians (i.e., surgeons) did not allow LEV to be used. This was included as one of the choices of why our respondents do not use LEV, but only 7% of laser surgery respondents and 12% of electrosurgery respondents reported this as one of their reasons. In addition, many respondents (27% of the 245 who wrote in an answer) responded something to the effect that they did not feel they had any control over whether LEV was used—"surgeons don't like it," "was not set up to use," "medical director does not think surgical smoke is hazardous." Some of these other answers reflect reasons reported in the literature for disuse, including expense, inconvenience, noise, and a general lack of knowledge regarding the potential hazards associated with exposure to surgical smoke [Bigony, 2007].

Similar proportions reported using wall suction versus a smoke evacuator for laser surgery while wall suction was more often used when smoke was removed during electrosurgery. Several sources [NIOSH, 1996; ANSI, 2005; Novak and Benson, 2010 Edwards and Reiman, 2012; Harkavy and Novak, 2014] report that with low volumes of smoke a wall suction is adequate, but with larger volumes a smoke evacuator is necessary. We did not ask respondents to comment on the amount of surgical smoke generated or what types of procedures were being performed, so we cannot determine whether the most appropriate type of LEV was used.

Although much less desirable according to the hierarchy of controls than LEV (an engineering control) [Manuele, 2005], PPE could be used to reduce exposure to surgical smoke [Harkavy and Novak, 2014]. Despite limited LEV use, though, few respondents reported use of respirators, indicating they were not in their protocol. The main other reason given for not using respirators was that either laser masks or standard surgical masks were worn; however, neither laser masks nor surgical masks are certified by NIOSH as respiratory protection.

Surgical smoke has been shown to cause eye irritation although no clear consensus exists for what protective eyewear should be worn. Despite this, more respondents wore protective eyewear than reported LEV, 74% of those working during laser surgery always wore protective eyewear, possibly to protect from tissue or fluids and laser beam and not necessarily the surgical smoke. For electrosurgery, 39% reported wearing protective eyewear. The higher proportion wearing protective eyewear might reflect personal volition, whereas many felt they did not have any control over whether LEV was used, they could decide whether or not to use goggles or face masks. Effective LEV would eliminate the smoke before eye exposure would occur.

Overall limitations of the survey are discussed in previous publications and include that the survey, as a whole, was not a representative sample of all healthcare workers but a targeted sample of members of professional practice organizations whose members were likely to be exposed to certain chemical agents. Response rate cannot be calculated because classes of chemical agents under study were specified in the invitation email and eligibility was based on whether or not invitees used or came in contact with specific hazardous chemicals on the job; it is unknown who decided not to participate because they did not use or come in contact with any of the chemicals versus those who used them but decided not to participate for other reasons. Therefore, we cannot generalize our results to all locations where surgical smoke is generated. Data are self-reported and not independently confirmed. Specific to this module on surgical smoke, no information was collected on type of procedure, amount of smoke generated and whether or not it was adequately controlled. Finally, respondents who reported they used "a different system" in place of LEV, were not queried as to what the other system might have been.

CONCLUSIONS AND RECOMMENDATIONS

LEV use is not widespread for controlling surgical smoke despite authoritative guidelines and recommendations from diverse professional, consensus, and governmental organizations

stating that surgical smoke should be evacuated at the source to prevent worker and patient exposure to chemical and biological toxicants. Respondents who reported receiving training on the hazards of surgical smoke and procedures addressing this hazard were more likely to report that LEV was always used, which may reflect management commitment to employee health. On the other hand, a high proportion of those who reported that LEV was not always used said it was because it was not part of their protocol and not provided by their employer. Even when LEV was not used, respondents did not use respirators as a replacement for LEV but reported use of standard surgical masks and laser masks which do not provide respiratory protection.

Employers should develop standard operating procedures that include recommendations by industry, standard setting, and government organizations, which stipulate use of LEV for all procedures where surgical smoke is generated (electrosurgery and laser surgery). These health and safety procedures would protect all healthcare personnel in the surgical suite/area from exposure to surgical smoke. Use of LEV should not be at the discretion of individual healthcare practitioners since many others are exposed including those anesthesiology professionals, nurses, technologists, and technicians who took part in this survey. Overall, our results provide a valuable snapshot of existing practices at the time of our survey especially considering our large sample size and diversity of respondents. Study findings can be used to raise awareness of surgical smoke controls and the need for education programs promoting their use.

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TABLE I

Occupational, Employer and Exposure Characteristics of Respondents

Characteristic	Laser surgery (n[a]) percent[b]	Electrosurgery (n[a]) percent[b]
Occupation	(1,390)	(4,496)
Nurse	57	56
Nurse anesthetist	40	33
Perioperative nurse	14	19
Other nurse	3	3
Physician (anesthesiologist)	23	21
Technologist/technician	13	17
Surgical technologist	13	16
Other technologist/technician	<1	1
Surgical assistant	2	3
Anesthesiologist assistant	3	2
Dentist/other dental professional	1	<1
Time in current occupation	(1,387)	(4,492)
0–5 years	19	20
6–10 years	14	14
11–20 years	25	24
21–30 years	23	24
>30 years	18	17
Member of a Labor Union	(1,388)	(4,481)
Yes	8	9
Employer industry category	(1,389)	(4,490)
Hospital	82	83
Ambulatory healthcare services	17	16
Other	1	1
Size of employer—number of workers	(1,389)	(4,484)
<10	6	5
10–99	21	20
100–249	11	12
250–1,000	28	29
>1,000	34	34
Employer ownership type	(1,372)	(4,448)
For profit	46	45
Non-profit	41	43
Public sector	12	12
Employer location by population density	(1,390)	(4,497)
Large city (50,000 people or more)	62	59
Small city (fewer than 50,000 people)	18	21
Suburbs (developed areas adjacent to cities)	11	11

Characteristic	Laser surgery (n[a]) percent[b]	Electrosurgery (n[a]) percent[b]
Rural	8	9
Number of years (in career) working in areas where surgical smoke was generated	(1,391)	(4,498)
<1	2	2
1–5	15	15
6–10	15	15
11–20	26	25
>20	41	43
Number of days working within 5 feet of a source of surgical smoke in past week	(1,311)	(4,469)
1	71	10
2	15	12
3	7	21
4	4	20
5	3	30
6–7	1	7
Number of hours working within 5 feet of a source of surgical smoke in past week	(1,330)	(4,467)
<1	61	16
1–5	31	32
6–20	6	30
21–40	2	19
>40	1	3
Total number of procedures working within 5 feet of a source of surgical smoke in past week	(1,307)	(4,452)
1	52	5
2–5	42	26
6–10	4	32
11–25	1	29
>25	<1	7

[a]Number of respondents varied for individual items (i.e., number of eligible respondents less number who elected not to answer).

[b]Percents may not add up to exactly100% due to rounding.

TABLE II

Training, Employer Procedures, and Exposure Monitoring

	Laser surgery (n[a]) percent[b]	Electrosurgery (n[a]) percent[b]
Received training addressing hazards of surgical smoke	(1,391)	(4,495)
Yes, within the past12 months	23	24
Yes, more than12 months ago	29	32
Never	49	44
Employer has standard procedures addressing hazards of surgical smoke	(1,391)	(4,494)
Yes	30	31
No	31	29
I don't know	39	40
Exposure monitoring (e.g., air sampling) conducted in the past 12 months to assess workers' exposure to surgical smoke	(1,338)	(4,439)
Yes	7	5
No	36	36
I don't know	57	59

[a]Number of respondents varied for individual items (i.e., number of eligible respondents less number who elected not to answer).

[b]Percents may not add up to exactly100% due to rounding.

TABLE III

Use of Engineering Controls and PPE While Exposed to Surgical Smoke

Type of control	Laser surgery (n[a]) percent[b]	Electrosurgery (n[a]) percent[b]
Engineering control		
How often was local exhaust ventilation used?	(1,315)	(4,436)
Always	47	14
Sometimes	22	26
Never	31	59
Type of local exhaust ventilation	(904)	(1,793)
Portable smoke evacuator	58	44
Room (wall) suction	55	75
Both	13	18
Personal protective equipment		
Respirator (N95, half-facepiece air purifying respirator with particulate filter, powered air purifying respirator with particulate filter)	(1,305)	(4,400)
Always	6	1
Sometimes	4	3
Never	90	96
Respirators were fit-tested	(126)	(159)
Yes	63	64
Eye protection	(1,308)	(4,405)
Always	74	39
Sometimes	13	22
Never	13	39

[a]Number of respondents varied for individual items (i.e., number of eligible respondents less number who elected not to answer).

[b]Percents may not add up to exactly100% due to rounding.

TABLE IV

Reasons for Not Always Using LEV and PPE While Exposed to Surgical Smoke

	Laser surgery[a,b]			Electrosurgery[a,b]		
Reason	**LEV (n =679) %**	**Resp.[c] (n =1,201) %**	**Eye Prot. (n =333) %**	**LEV (n =3,761) %**	**Resp.[c] (n =4,275) %**	**Eye Prot. (n =2,667) %**
General room ventilation was sufficient to dissipate smoke	20	—[d]	—	29	—	—
Used a different system to remove smoke	21	—	—	36	—	—
An engineering control was being used	—	9	7	—	9	6
Not part of our protocol	28	48	21	33	56	30
Exposure was minimal	24	31	55	21	33	52
Not provided by employer	23	28	7	25	23	7
Not readily available in work area	16	24	10	18	23	10
No one else who does this work uses them	6	15	8	9	21	12
Not permitted by surgeon	7	—	—	12	—	—
Too uncomfortable or difficult to use	2	6	14	2	9	16
Too bulky or noisy	5	—	—	8	—	—
Concerned about raising the patient's anxiety	—	1	1	—	1	<1
Other	9	6	11	8	5	16

LEV, local exhaust ventilation.

[a]Columns add to more than100% because respondents were instructed to mark all that apply.

[b]Number of respondents varied for individual items (i.e., number of eligible respondents less number who elected not to answer).

[c]Choices included N95 respirator, surgical N95 respirator, half-facepiece air-purifying respirator with particulate filters, and powered air-purifying respirator with particulate filters.

[d]Dash (—) indicates this reason was not included as a response option.

TABLE V

Proportion Reporting LEV Always Used by Workplace and Employee Characteristic

% reporting LEV always used	Laser surgery			Electrosurgery		
	n	Percent	*P*-value	n	Percent	*P*-value
Received training addressing hazards of surgical smoke						
Yes, within the past12 months	297	61	<0.01[a]	1,093	21	<0.01[a]
Yes, more than12 months ago	385	53		1,405	12	
Never	632	37		1,936	12	
Employer has procedures addressing hazards of surgical smoke						
Yes	402	63	<0.01[b]	1,389	25	<0.01[b]
No	404	38		1,265	7	
I do not know	508	42		1,779	12	
Employer industry category						
Hospital	1,080	45	<0.01[b]	3,658	14	0.24[b]
Ambulatory healthcare services	218	62		727	16	
Size of employer—number of workers						
2–9	62	60	0.03[a]	190	24	<0.01[a]
10–99	270	52		895	17	
100–249	149	46		511	17	
250–1,000	374	43		1,260	14	
>1,000	450	47		1,522	11	
Employer ownership type						
For profit	592	50	0.09[b]	1,982	15	0.36[b]
Non-profit	543	44		1,885	13	
Public sector	161	48		518	15	
Employer location by population density						
Large city (50,000 people or more)	819	48	0.73[b]	2,603	14	0.05[b]
Small city (fewer than 50,000 people)	244	46		926	16	
Suburbs (developed areas adjacent to cities)	150	50		509	12	
Rural	100	43		395	17	

% reporting LEV always used	Laser surgery			Electrosurgery		
	n	Percent	*P*-value	n	Percent	*P*-value
Occupations with n >20						
Surgical technologist	169	55	0.21[b]	708	15	<0.01[b]
Surgical assistant	25	52		113	12	
Perioperative nurse	194	49		854	8	
Anesthesiologist	302	46		928	14	
Anesthesiologist assistant	36	44		87	11	
Nurse Anesthetist	522	44		1,480	16	
Gastroenterology/endoscopy nurse	–	–		63	19	
Number of years (in career) working in areas where surgical smoke was generated						
<1	31	52	0.15[a]	97	30	<0.01[a]
1–5	192	47		670	20	
6–10	194	44		658	16	
11–20	350	41		1,113	13	
>20	547	52		1,898	12	
Number of days working within 5 feet of the source of surgical smoke in past week						
1	920	51	<0.01[a]	431	29	<0.01[a]
2	198	44		548	18	
3	83	39		909	14	
4	44	30		897	10	
5–7 (laser surgery)	47	34				
5 (electrosurgery)				1,346	12	
6–7 (electrosurgery)				302	13	
Number of hours working within 5 feet of the source of surgical smoke in past week						
<1	792	51	<0.01[a]	712	25	<0.01[a]
1–5	412	45		1,424	15	
6–20	71	32		1,335	11	
>20 (laser surgery)	34	21				
21–40 (electrosurgery)				822	10	
>40 (electrosurgery)				140	11	

% reporting LEV always used	Laser surgery			Electrosurgery		
	n	Percent	*P*-value	n	Percent	*P*-value
Total number of procedures performed for which you were within 5 feet of the source of surgical smoke in past week						
1	678	51	<0.01[a]	231	32	<0.01[a]
2–5	547	46		1,160	21	
6–10	54	35		1,439	11	
>10 (laser surgery)	22	23				
11–25 (electrosurgery)				1,294	11	
>25 (electrosurgery)				310	12	

[a]Mantel–Haenszel Chi-square was calculated for ordinal variables.

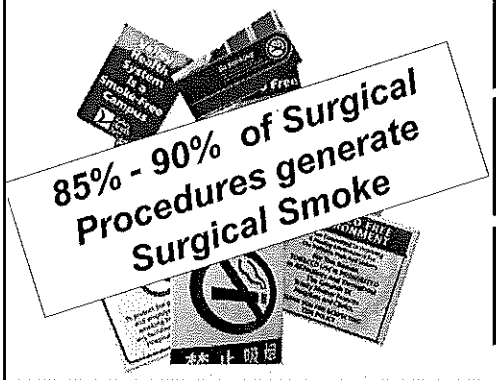
[b]Pearson Chi-square was calculated for nominal variables.

Am J Ind Med. Author manuscript; available in PMC 2017 November 01.

Methods of Protection & Cost of Service

APPENDIX III

What is in Surgical Smoke?



70% of particulate in surgical smoke <0.3um in size

150 chemicals found in surgical smoke

Benzene, Hydrogen Cyanide, Formaldehyde, etc.

Viable HPV, HIV, Hep B Virus have been recovered in plume.

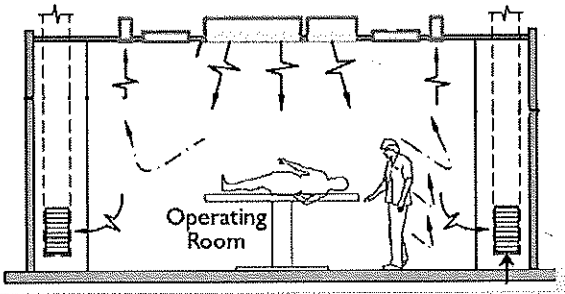
Documented cases of cancer from surgical plume

APPENDIX III

Dissemination of Smoke Particles

Particulate matter distribution is uniform throughout the OR. A person standing several feet from the sterile field can inhale as much smoke as the surgical team...travels via kinetic energy, within 5 seconds there are million of particles

Travels at 40 mph increasing particulates from a baseline of 60,000 to 1 million particles per cubic foot...20 minutes with OR air flow to return to baseline



Operating Room Air Circulation

APPENDIX III

General Operating Room Ventilation

Table B.2. Ventilation requirements for areas affecting patient care in hospitals and outpatient facilities[1]

Format Change [February 2017]

⚠ The format of this section was changed to improve readability and accessibility. The content is unchanged.

Surgery and critical care

Area designation	Air movement relationship to adjacent area[3]	Minimum air changes of outdoor air per hour[3]	Minimum total air change per hour [4,5]	All air exhausted directly to outdoors[6]	Recirculated by means of room units[7]	Relative humidity[8] (%)	Design temperature[9] (degrees F [C])
Operating/surgical/cystoscopic rooms[10, 11]	Out	3	15	-	No	30-60	68-73 (20-23)[12]
Delivery room[13]	Out	3	15	-	No	30-60	68-73 (20-23)
Recovery room[13]	-	2	6	-	No	30-60	70-75 (21-24)

APPENDIX III

General Operating Room Ventilation

1. Airborne Contaminant Removal

Table B.1. Air changes/hour (ACH) and time required for airborne-contaminant removal by efficiency *

Air Exchanges

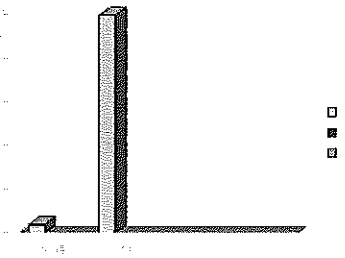
Minutes to Baseline

ACH § ¶	Time (mins.) required for removal 99% efficiency	Time (mins.) required for removal 99.9% efficiency
2	138	207
4	69	104
6'	46	69
8	35	52
10'	28	41
12'	23	35
15'	18	28
20	14	21

APPENDIX III

Wall/Canister Suction

- **Corrodes pipes**
  Contaminates building
- **Flow may not be high enough to capture surgical smoke...**

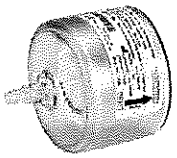


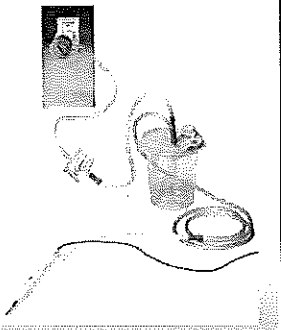
Wall Suction 2 Cubic Foot per Minute
Evacuator 30-70 Cubic Foot per Minute

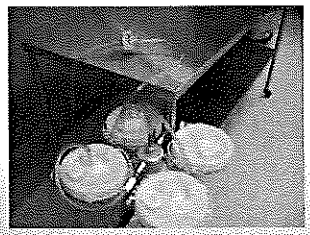
APPENDIX III

Wall Suction: 0.1 µm ULPA Filter Hook-Up in Every Operating Room

- By-pass the filter in the canister…will compromise cfm
- …and assignment of filter change weekly



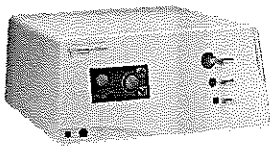


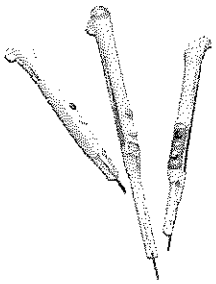


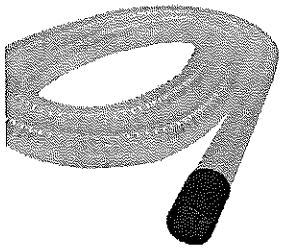
In-line filter should be used when wall suction is chosen….best practice is in all rooms

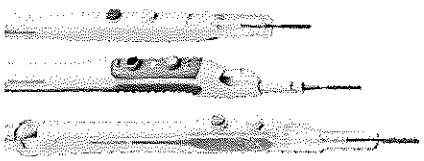
APPENDIX III

Smoke Evacuation Systems



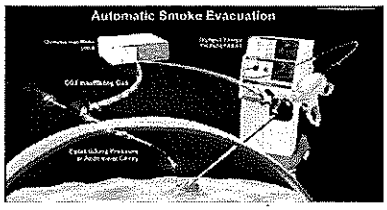


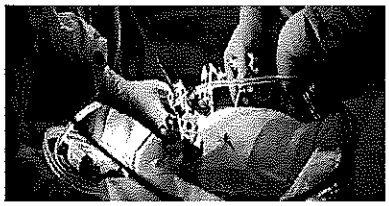


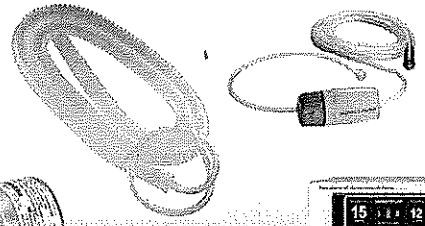


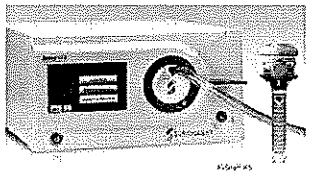
APPENDIX III

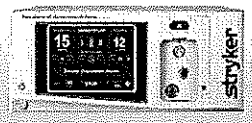
Laparoscopic Filtration











APPENDIX III

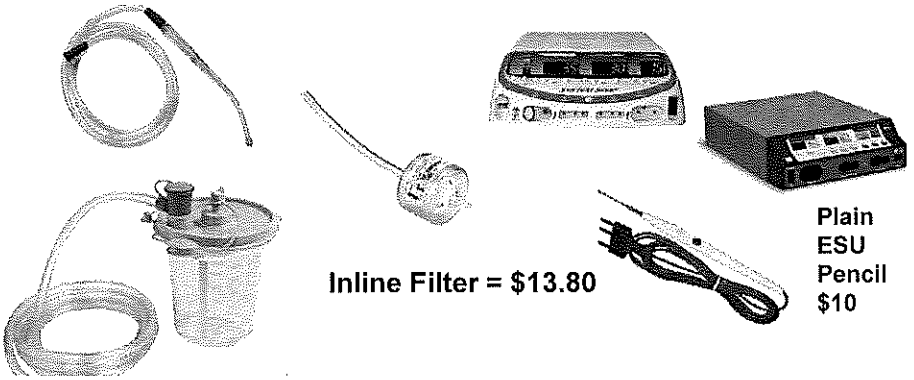
Cost Effective Options to Evacuate & Filter Surgical Smoke

Smoke Supply Invoice

Item	Item Type	Quantity Ordered	UOM	Unit Cost	Extended Cost	Distributions	Activity / Account Category	Distribution Allocation	Requested Delivery Date	Sourcing Event Required	unit cost
37944	Nonstock	1	CS(10)	440.0000	440.0000	2657062110-067300-0000		100.0%		No	($22)
FILTER PENCIL PLUMEPEN SMOKE / EVACUATN Vendor : COVIDIEN Vendor Item : CVPLP2000											
[redacted]											
93817	Nonstock	1	CS (24)	208.2800	208.2800	2657062110-067300-0000		100.0%		No	($8.68)
TUBING SMOKE EVACUATOR 10FT / 7/8IN 8IN WAND Vendor : MEDTEK DEVICES INC											
[redacted]											
100424	Nonstock	1	CS (10)	138.4100	138.4100	2657062110-067323-0000		100.0%		No	($13.80)
FILTER SMOKE EVACUATOR ALL DAY / 8/ILN REPL .IM Vendor : MEDTEK DEVICES INC											lasts ~7 days
[redacted]											$1.97 / day
Totals: 3 Lines		3			786.69 USD						

APPENDIX III

Option 1: Least Expensive $1.97



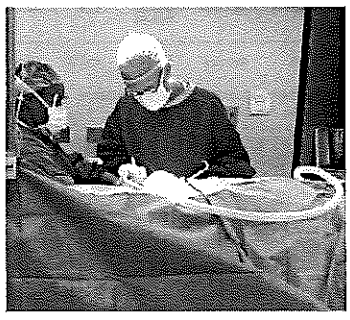
Inline Filter = $13.80

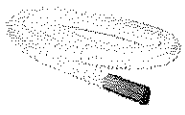
Plain ESU Pencil $10

Least Expensive Option: Inline Filter. Lasts 7 days (or longer) at $1.97 per OR per day

Option 2: Smoke Evacuator + Tubing = $10.25

- Smoke Evacuator Cost: $2000.00
- Amortized over 5 years
- Cost per year = $400.00
- 252 workdays in 2020
- $1.59 per day per machine

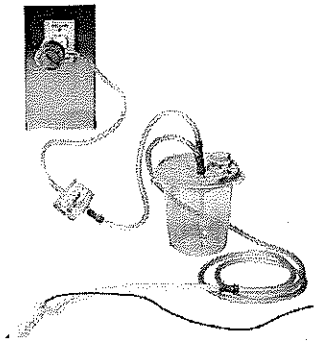




7/8" Sterile Tubing = $8.66

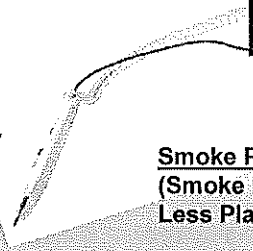
7/8" Non Sterile Tubing = $6.86

Option 3: .1 Inline Filter + Smoke Pencil = $13.97



Inline Filter $1.97 per day

Inline Filter + Smoke Pencil = $13.97

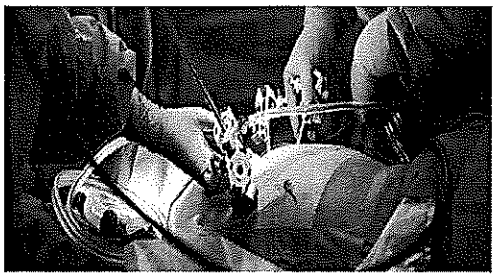


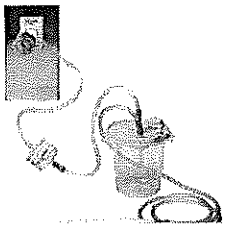
Smoke Pencil = $12
(Smoke Pencil = $22,
Less Plain ESU Pencil=$10)

APPENDIX III

Option 4: Laparoscopic Procedures + $11.97

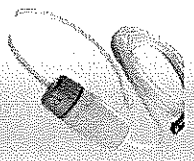
Laparoscopic filter $10





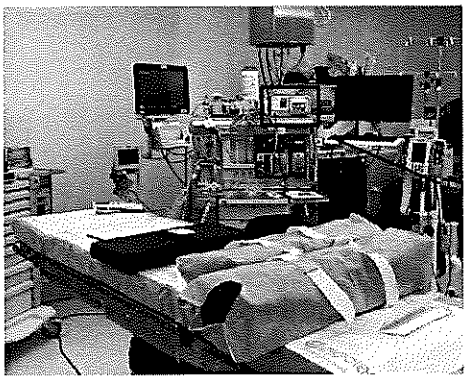
Inline Filter $1.97 per day

Laparoscopic filter $10 = Inline Filter $1.97 = $11.97



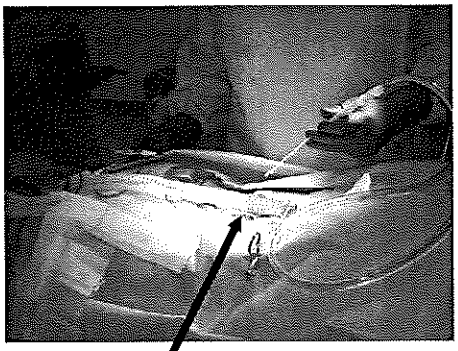
APPENDIX III

Anesthesia: Intubation & Extubation



APPENDIX III

Algorithms per Service



Neurosurgery Soaker Hose

General

APPENDIX III

MAUD: Manufacturer and User Facility Device Experience

1. Smoke evacuator stopped functioning
   a. **No patient injury reported**
   b. **Note: 22 reports from same manufacturer**
   c. **N=23**
2. Electrosurgery device stayed activated
   a. **No patient injury reported**
   b. **N=3**
3. Electrosurgery device tip caught fire/arced
   a. **No patient injury reported**
   b. **N=2**
4. Electrosurgery pencil burned hole in holster
   a. **No patient injury reported**
   b. **N=1**
5. Plastic on electrosurgery pencil noted falling apart
   a. **No patient injury reported**
   b. **N=1**
6. Air channel on electrosurgery pencil broke off
   a. **No patient injury reported**
   b. **N=1**
7. Error message received during set up
   a. **No patient injury reported**
   b. **N=1**
8. Post-op bleeding following mastectomy with electrosurgery pencil with smoke evacuation
   a. **Patient returned to surgery for hematoma drainage**
   b. **N=1**

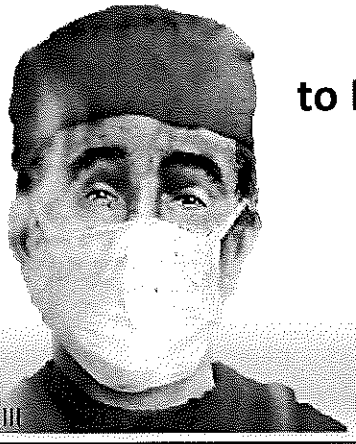
APPENDIX III

Cost of Smoke Evacuation

- **Costs vary based on:**
  - Buying group prices
  - Equipment selected
  - Accessories used
  - Options are available
  - Doesn't have to be expensive
  - Manufacturers may place equipment for disposable supply use

APPENDIX III

A Small Price to Pay…



to Breathe Clean Air

APPENDIX III

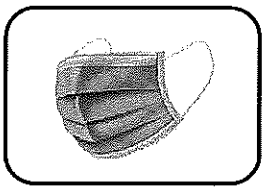
Respiratory Protection: Health Care Workers

Christopher Hudgins, BS, ASN, RN, CNOR

- Georgia Council of Perioperative Registered
  - Legislative Committee
  - Board of Directors
- AORN Atlanta Chapter 1101
  - Board of Directors
  - Past President
- 27 Years Health Care Experience

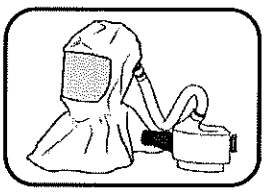
APPENDIX IV

Respiratory Protection - Options

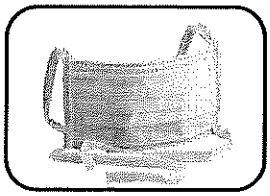


Procedural Mask

Elastomeric Respirators



Powered Air Purifying Respirator (PAPRs)



Surgical Masks

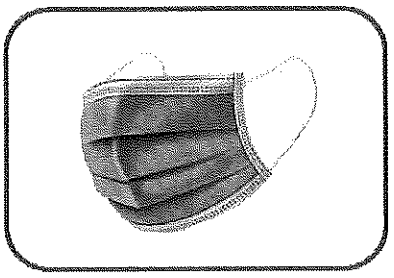
Filtering Facepiece Respirators (FFRs)

APPENDIX IV

Respiratory Protection

Procedure Masks

- Single-use
- Disposable
- Not fluid resistant
- Protects the patient and the work environment
- *Not tested and certified to provide respiratory protection*



Procedure Masks should not be used in a sterile surgical field.

APPENDIX IV

Respiratory Protection

Elastomeric Respirators

- Can be cleaned and reused
- Fits tightly to the face
- Wearer needs to be clean shaven
- Requires annual fit testing

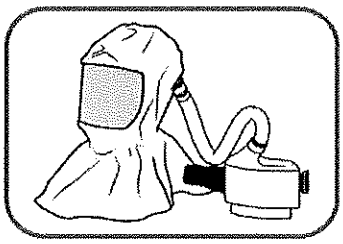
Elastomeric Respirators should not be used in a sterile surgical field.

APPENDIX IV

Respiratory Protection

Powered Air Purifying Respirators (PAPRs)

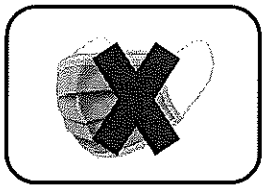
- Most can be cleaned and reused
- Some fit over some facial hair
- No fit testing required
- Comes with a battery and belt



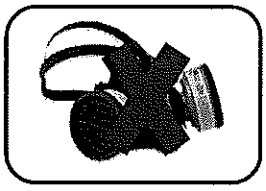
Powered Air Purifying Respirators should not be used in a sterile surgical field.

APPENDIX IV

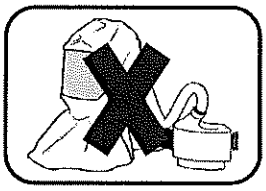
Respiratory Protection - Options



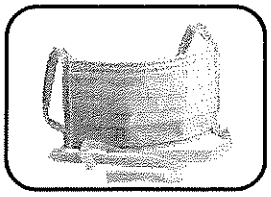
Procedural Mask



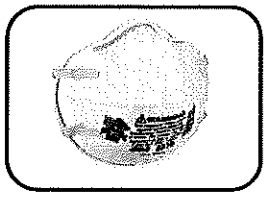
Elastomeric Respirators



Powered Air Purifying Respirator (PAPRs)



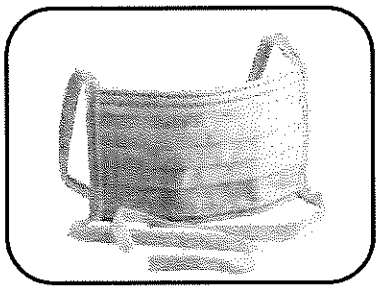
Surgical Masks



Filtering Facepiece Respirators (FFRs)

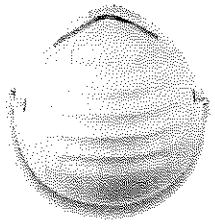
APPENDIX IV

Respiratory Protection



Surgical Masks

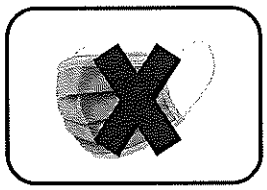
- Single-use
- Disposable
- Fluid resistant
- Protects the patient and the work environment
- *<u>Not</u> tested and certified to provide respiratory protection*



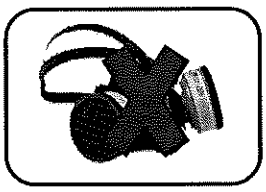
Surgical Masks can be used in a sterile surgical field, but not for respiratory protection.

APPENDIX IV

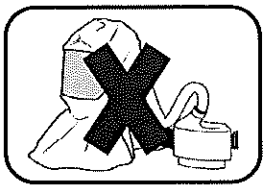
Respiratory Protection



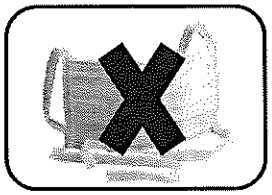
Procedural Mask



Elastomeric Respirators



Powered Air Purifying Respirator (PAPRs)



Surgical Masks

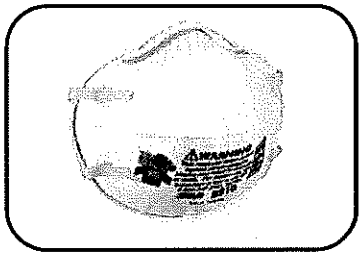
Filtering Facepiece Respirators (FFRs)

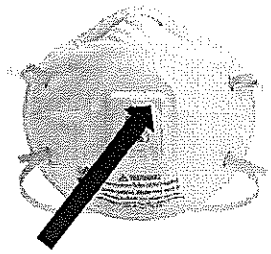
APPENDIX IV

Respiratory Protection

Filtering Facepiece Respirators (FFRs)

- Single-use
- Disposable
- With and without exhalation valves
- Protects the patient and the work environment
- Reduces the wearer's exposure to airborne hazards





Exhalation Valve

APPENDIX IV

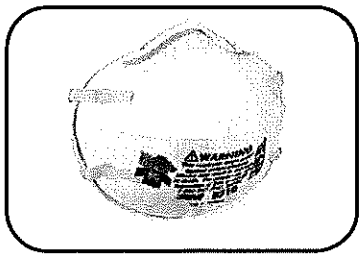
Respiratory Protection

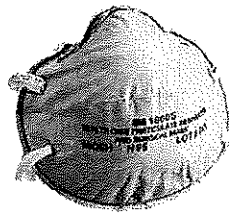
N95s: A type of filtering facepiece respirator

Surgical N95: N95 that is fluid resistant

Drawbacks for health care workers in the OR

- Tight fit to wearer's face
- Can be hot and difficult to breathe through
- Wearer must be medically cleared & fit tested to wear
- Wearer should not have any facial hair
- Provides ≥ 95 % filtration efficiency against particulate hazards
  - Only when fit tested and worn properly (no gaps)
  - Does not remove 100% of smoke





APPENDIX IV

Respiratory Protection

CDC Website:

The requirements for surgical N95 respirators that make them resistant to high velocity streams of body fluids and help protect the sterile field can result in a design that has a higher breathing resistance (makes it more difficult to breath) than a typical N95 respirator.

APPENDIX IV
https://www.cdc.gov/coronavirus/2019-ncov/hcp/respirator-use-faq.html

Respiratory Protection

Study: Prevalence of Adverse Skin Reactions

2003 SARS Outbreak

N95 Respirator Use

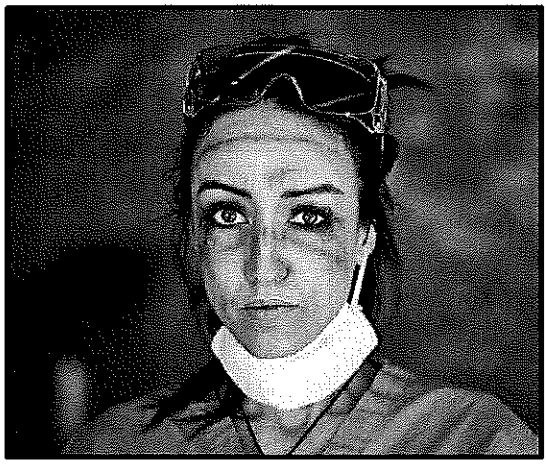
(Average: 8 hours a day | Mean: 8.4 months)

- 35% Reported Adverse Skin Reactions
  - Acne = 59.6%
  - Facial Itch = 51.4%
  - Rash = 35.8%

Foo, Chris C I et al. "Adverse skin reactions to personal protective equipment against severe acute respiratory syndrome--a descriptive study in Singapore." *Contact dermatitis* vol. 55,5 (2006)

APPENDIX IV

Respiratory Protection



APPENDIX IV

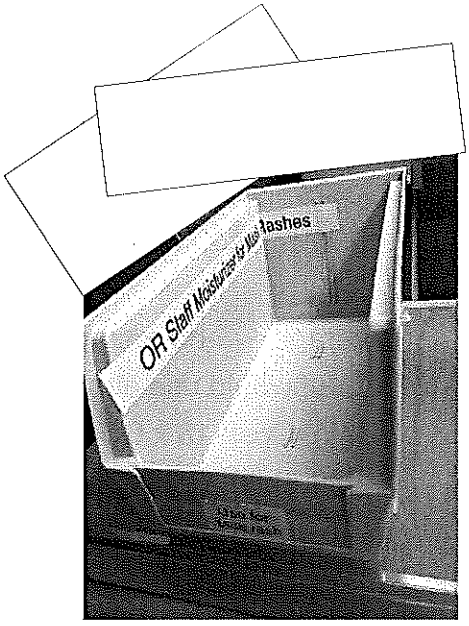
Reproduced with permission from AORN.

Respiratory Protection

Picture = Georgia Acute Care Hospital

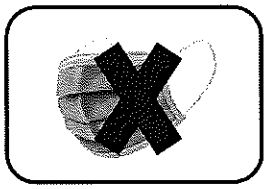
- Bin for packets of facial moisturizing lotion the Operating Room
- Label States:
  - OR Staff Moisturizer for Rashes
  - Use for Face Rashes

- Note: An employee in the operating room at a local hospital could not work recently due to a severe irritation on the face from wearing FFRs.

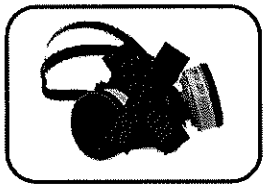


APPENDIX IV

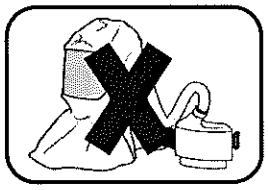
Respiratory Protection



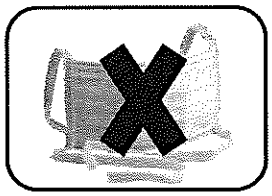
Procedural Mask



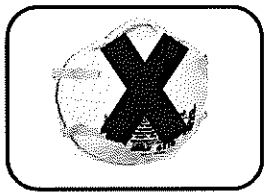
Elastomeric Respirators



Powered Air Purifying Respirator (PAPRs)



Surgical Masks



Filtering Facepiece Respirators (FFRs)

APPENDIX IV

Respiratory Protection

Costs: N95s

- ~56 cents each

Average 4-5-hour surgical procedure

- Staff would use about 16 N95s
- Mfg. Cost: 16 x 0.56 = $ 8.96
- Distributor Price: 8.96 x .03 = $ 9.22

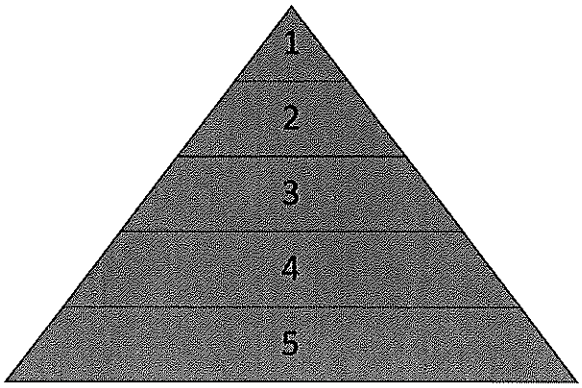
Cost source: U.S. Sales Leader for a major manufacturer of N95s.
N95 estimated use: Christopher Hudgins

APPENDIX V

Staff in Operating Rooms

Anesthesiologist
Anesthesia Provider (CRNA/PA)
Relief Anesthesia Provider
Anesthesia Assistants
Circulating Nurse
Relief Circulating Nurse
Surgical Technician
Relief Surgical Technician
Nursing Assistant
Medical Students
Residents
Nursing Students
Sales Representatives
Clinical Educators
Surgical Assistant (RNFA/PA)
Surgeon
2nd Surgeon

Respiratory Protection



5 -> Personal Protective Equipment (PPE)

- Respiratory protection

OSHA's Hierarchy of Controls

APPENDIX IV

Adopted from AORN Guidelines 2020.

Respiratory Protection

Surgical Smoke Evacuation Legislation

The only way to protect health care workers in the Operating Room!

APPENDIX IV

Questions?

APPENDIX IV

Official publications of the Association of Cutaneous surgeons of India (ACSI)
Journal of Cutaneous and Aesthetic Surgery
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Current issue
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J Cutan Aesthet Surg. 2019 Jan-Mar; 12(1): 1–7.
doi: 10.4103/JCAS.JCAS_177_18: 10.4103/JCAS.JCAS_177_18
PMCID: PMC6484569
PMID: 31057262

Surgical Smoke in Dermatology: Its Hazards and Management

Saloni Katoch and Venkataram Mysore[1]

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[1]Director and Consultant Dermatologist, Venkat Charmalaya-Center for Advance Dermatology and Post Graduate Training, Bengaluru, Karnataka, India
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Abstract

Surgical plume with vaporized tissue particles, pathogens, and toxic gases emanating during dermatosurgical procedures is an occupational hazard to the dermatosurgeon, and protective measures must be taken to prevent their inhalation. Smoke evacuators are devices that capture and filter the plume generated during electrosurgical procedures or laser procedures, thereby maintaining a safe environment for the surgical team and the patient. A smoke evacuation system should be appropriately selected depending on the need of the facility. The objective of this article is to outline the health hazards of the smoke by-product of electrosurgery and lasers and provide details about safety measures and smoke evacuation systems.

Keywords: Filters, hazards, smoke evacuators, surgical smoke
Key messages: Surgical smoke is a biochemical hazard comparable to chronic second-hand smoking. Constant exposure can result in serious health issues for the doctor, supportive staff, and patient. Despite conclusive evidence, smoke evacuators are seldom used in a dermatology clinic. The importance of smoke evacuation is probably underemphasized and should be strictly implemented in dermatology clinics for a safe working environment.

Introduction

Electrosurgical and laser procedures are regularly performed in a dermatology clinic and generate smoke that can be harmful to the doctor, nurses, and the patient. With the frequency of these procedures increasing every year and with mounting evidence about the hazards of surgical plume, maintaining a smoke-free environment is becoming very important. Surgical smoke comprising 95% water and 5% particulate matter is produced as a by-product when there is thermal destruction of target cells leading to rupture and release of cellular contents. It poses significant risk as a respiratory tract irritant and mutagen, and as a vector for infectious particles.[1] Surgical plume has been compared to smoking unfiltered cigarettes, with electrosurgical plume being twice as harmful as compared to lasers, hence making its

APPENDIX V

complete evacuation necessary.[2] Although several guidelines and articles have been published about smoke evacuation in the Western literature, there is paucity of publications in Indian literature. This article aims at discussing methods and proposed strategies to minimize the hazards of surgical smoke.

Risks of Surgical Smoke

Exposure to toxic organic compounds and infectious particles in surgical smoke can lead to burning and irritation in the eyes, pulmonary effects, risk of transmission of infection, and carcinogenesis. Table 1 shows the risks of surgical smoke.

Lack of knowledge and underuse of protective equipment make doctors and health care providers with long-term exposure susceptible to its biohazards.[1] Particulate matter of the plume include both noninfectious and infectious matter and are discussed later:

1. Size

Around 77% of particulate matter within surgical smoke was found to be less than 1.1 μm in size. Electrosurgical devices and lasers create particles of roughly 0.07 and 0.31 μm, respectively. Deposition of particles in the bronchioles and alveoli can take place when the size is less than 2 μm, leading to chronic irritation, emphysema, interstitial pneumonia, and bronchitis. Standard surgical masks can filter particulate matter greater than 5 μm in size and hence do not provide any protection against electrosurgical and laser plume.[3,4,5,6] Table 2 depicts comparison between electrosurgical and laser plume.

2. Odor

Tissue pyrolysis and destruction leads to release of toxic gases that impart a noxious odor to the surgical plume. Chemical contents of the electrocautery plume are mostly hydrocarbons, phenols, nitriles, and fatty acids. Some of these organic compounds such as acrylonitrile, benzene, butadiene, toluene, acrolein, and formaldehyde have been identified as carcinogens. Tissue oxygenation is affected adversely with compounds such as hydrogen cyanide and carbon monoxide. Effects of short-term exposure to acrylonitrile and benzene include eye irritation, nausea, vomiting, headache, dizziness, weakness, and light headedness, whereas chronic exposure can result in higher incidence of cancer.[1,2,7,8,9] Carbon monoxide, hydrogen cyanide, formaldehyde, benzene, and acrolein are also present in plume associated with ablative lasers.[10]

3. Viability and infectious hazards

Presence of infectious particles such as human papillomavirus and bacteria in surgical smoke has been studied with viral transmission being demonstrated in animal studies. Aerosolization of viral particles in the plume of CO_2-laser-treated warts has been confirmed as early as 1988 by Garden *et al.*[11] Two cases of laryngeal papillomatosis in health care professionals secondary to treatment of anogenital condyloma acuminata with electrodessication and laser have also been reported.[12,13] Viable bacteria such as *Staphylococcus*, *Corynebacterium*, and *Neisseria* have also been detected in plume associated with laser resurfacing.[14] Presence of HIV proviral DNA was also reported in vaporous debris from CO_2-laser-treated HIV infected tissue culture pellets by Baggish *et al.*[15] Viable bacteria and viruses have been demonstrated on electrosurgical electrodes, thereby proving that the electrical discharge does not sterilize the electrode and is capable of creating an aerosol of blood and tissue droplets that can transfer infectious agents. An *in vitro* study has identified the presence of viable malignant cells in surgical smoke, thereby reflecting the importance of smoke evacuation and respiratory protection while treating cutaneous malignancies.[16]

The infectious and noninfectious hazards of surgical plume are enumerated in Tables 3 and 4, respectively.

Methods of Hazard Reduction

In practice, many dermatologists do not routinely adopt protective measures while using lasers or electrocautery despite conclusive evidence against its potential biohazards. Basic precautions include good general room ventilation, masks, suction, smoke evacuators, and protective eye glasses.

Protective measures can be divided into the following:

Respiratory protection

1. Standard surgical masks

Routine surgical masks are useful but not sufficient. They offer protection against particulate matter of size greater than 5 μm and have a reported filtration efficiency of 91.53%. Most of the particulate matter in surgical plume is less than 1.1 μm in size and hence high-filtration masks have been developed to offer more protection.

2. High-efficiency particulate air (HEPA) or laser masks

HEPA respirator masks such as N95 have a filtration efficiency of 99.93% and offer more protection in comparison to disposable surgical masks as they can filter submicrometer-sized particles. These can be used adequately against residual plume that escapes the smoke evacuation system and are not a replacement for smoke evacuation devices. A proper fitting mask that covers both the nose and mouth should be used.[17,18,19]

Exhaust ventilation procedures

General ventilation: General ventilation, also referred to as dilution ventilation, controls the environment by diluting and replacing contaminated air before concentration of chemicals reaches unacceptable levels. Mechanical ventilation by exhaust fans slowly removes contaminants dispersed in the air and is suited for procedures with low and uniform rate of smoke generation. Its disadvantage includes dispersion of particulate matter from the source into the working environment, thereby exposing the health care professional and patients to the hazardous plume and odor. It is best used in conjunction with smoke evacuation devices to remove surgical plume that may have escaped the capture device. General exhaust ventilation is depicted in Figure 1.

Local exhaust ventilation (LEV): LEV procedures are designed to capture and remove smoke from the site of emission, thereby minimizing exposure to contaminants. Figure 2 illustrates the principle of an LEV. The following systems work on the principle of LEV:

1. Room suction systems

These can be used for procedures that produce small amounts of plume as the air movement generated may only be about 2 cubic feet per minute. A filter needs to be placed in the existing wall suction line between the suction canister and wall connection to purify the air; otherwise the surgical smoke can corrode the suction pipes and cause contamination. The in-line filter should be changed according to the manufacturer's instructions and contaminated filters should be disposed properly.[20,21] Standard suction systems with in-line filters are an inexpensive method of surgical smoke evacuation in an outpatient setting where procedures of shorter duration generating small quantities of smoke are performed. Figure 3 illustrates a schematic diagram of the wall suction unit with an in-line filter.

2. Smoke evacuator

A smoke evacuator is a system comprising a vacuum pump and filters that capture and purify surgical smoke generated during a procedure and return it to the operating room. It should be highly efficient in reduction of airborne particulate matter. It is necessary for procedures where larger amounts of smoke are

produced as the air movement generated is about 35–50 cubic feet per minute. It is recommended for procedures involving verrucae, large epidermal nevi, laser ablation, and laser hair reduction. It comprises the following parts:

a. Suction unit or vacuum source

The suction power of a smoke-evacuating system is its ability to generate a threshold minimum volume of airflow. A minimum airflow of 0.012–0.017 m^3/s was recommended by Hunter [22] for electrocautery smoke whereas a higher minimum airflow may be required for procedures like laser hair reduction creating larger volume of plume. The machine can have different types of pumps that determine the suction power generated by the smoke evacuator.[22,23] Types of pumps are as follows:

I. Turbine pump (10 A): It moves air at 60L/min after a delay of 3s. There is no occlusion feature to shut off the unit even if the evacuation tubing gets clogged. More efficient pumps are now available.

II. Rotary vein pump (2 A): This is a small powerful pump with suction five times greater than the turbine pump. It is more efficient in air movement and creates an instant negative pressure. It also shuts off the unit if the tubing gets occluded.

b. Filter

Filtration efficiency of a smoke evacuation system is very important. It depicts the number of particles that pass through the filter.

Types of filters include the following:

I. Charcoal filter: Activated charcoal is capable of absorbing gas and vapor. It helps in elimination of strong-smelling gases. Coconut shell charcoal is better at absorbing particulate matter in comparison to wood-based charcoal due to greater internal pore area.

II. HEPA: It is used to filter suspended compounds. It retains 0.3-μm-sized particles at an efficiency rate of 99.97%.

III. Ultra low particulate air (ULPA): It is more powerful than HEPA and retains ultrafine particles sized 0.1 μm with an efficiency rate of 99.9999%. It is a depth filter where matter is filtered by different methods depending on the particle size. This type of filter is found in smoke evacuators today.

A combination of charcoal filter and ULPA filter provides the best filtration. The charcoal filter is used to remove the noxious odor and toxic gases whereas ULPA filter retains the ultrafine particles. The particulate matter is filtered by different methods depending on its size. Particles greater than 1 μm are directly intercepted as they are too large to pass through the filter. Inertial impaction helps in capture of particles sized 0.5–1 μm as they collide and stay over the fibers. Diffusional interception captures particles less than 0.5 μm in size as these particles owing to Brownian motion look out and stick to the fibers. The most penetrating particle is that of size 0.12 μm as it does not exhibit the random motion to be trapped by diffusional interception. HEPA filters are no longer adequate as they trap particles of size 0.3 μm and above.[21,23,24]

Change of filter: Most of the evacuation devices have an inbuilt alarm or an indicator light to signal a required change. A change of filter is mandated when the suction pressure decreases or there is a lingering odor in the air. The contaminated filter may be considered as infectious or regulated waste depending on the waste disposal protocol of the facility.[23]

c. Smoke tubing

These are available in varying sizes depending on the amount of smoke that needs to be evacuated. With the same suction strength, a tubing with a wider internal diameter may increase the airflow by 5–10%. A smooth inner lumen will further decrease the whistling noise produced by corrugated tubes.[25] Reducer fittings that connect a smaller suction tube attached with the electrosurgical instrument to a larger smoke evacuation tubing are also available.[23]

d. Inlet nozzle, smoke capture devices

The inlet nozzle of the tubing should be held close to the site of smoke generation to capture maximum plume. Many devices such as evacuation wands and pencils, which can attach to the electrosurgical and laser equipment, are available for thorough and adequate smoke capture. A 2.2-cm wand when placed at a distance of 7.5cm from the smoke source captured only 53% of the smoke in comparison to 99% capture when placed at 2.5cm.[25] A standard electrosurgical unit (ESU) pencil has an internal diameter of 1cm and incorporates the smoke tube for plume evacuation at the tissue impact site.[19] It activates when the ESU pencil is in use and unlike the traditional handheld nozzle does not have to be held by the surgical team members.

e. Others

Foot pedals can be used for turning the system on and off. Alternatively, automatic activation devices can be used, which turn on the evacuator when the electrosurgical or laser equipment is being used. Some systems also have an electronic control panel to facilitate and maintain functions.

Table 5 enumerates the importance of a smoke evacuator. The basic model of a smoke evacuator with an inlet, tubing, and suction unit is depicted in Figure 4.

3. Centralized smoke evacuation

The plume here is collected in a central area for filtration via tubing attached to different surgical rooms. This system involves regular cleaning and flushing of internal tubing to prevent accumulation of particulate debris and pathogen growth. A failure of the central system will render smoke evacuation ineffective in all the connected surgical rooms.[23] This system is best suited for an inpatient facility where multiple open procedures are performed and may not be ideal and cost-effective for an outpatient setting.

Evaluation of smoke evacuators before purchase[19,23,26,27,28,29]: Before purchasing a smoke evacuator, a comprehensive evaluation of the following should be performed. Criteria for a good smoke evacuator are enumerated in Table 6.

1. Filtration efficiency: Most current smoke evacuators use ULPA filters.
2. Flow rate: A minimum flow rate 0.012 m^3/s is recommended and depends on the type of pump. A system with variable flow rate settings covers broad range of procedures.
3. Noise level: A noise level of 60 Db or less is recommended and depends on the size of the tubing and the condition of foam padding in the smoke evacuator. Corrugated tubes produce more noise.
4. Mobility: An easily mobile smoke evacuator can be moved from one room to another.
5. Cost-effectiveness: Disposables such as filters, tubing, and nozzles will have to be purchased on a continual basis. Economical replaceable prefilters are now available to minimize wear and tear of the main filtration unit. The cost may vary depending on the company and the type of smoke evacuator model chosen.
6. Maintenance: Maintenance should be simple and should be performed regularly as per the manufacturer's instructions.

7. Supplies and accessories

The Indian Association of Dermatologists, Venereologists and Leprologists guidelines for setting up a laser room and dermatosurgery theatre recommend use of surgical masks with a pore size of less than 1 μm, use of a smoke evacuator with a HEPA filter while treating verrucae or large epidermal nevi and an inlet nozzle with a capture velocity of 100–150 feet per minute held 2 inches above the operation site.[30,31]

Education

Awareness and knowledge are the keys in bringing about a change in the attitude of dermatologists toward the risk of exposure to noxious and hazardous surgical plume and their potential adverse effects. Incorporating the above subject in the residency curriculum will help in an understanding and promotion of safe smoke evacuation methods. Continuing education of the entire surgical team is a very important step in minimizing and eliminating surgical plume.[19]

Conclusion

Exposure to surgical plume has been found to have the same effect as chronic second-hand smoking. Despite the health hazards, standard of care and protective measures in dermatology clinics are not adequate. Objective data have confirmed the risk of direct physical injury, infection transmission, and mutagenesis in animals; more studies are required in human populations to investigate the aforementioned concerns. We recommend that prevention of inhalation of surgical plume should be of utmost importance to the dermatologist and the supporting staff. With mounting medicolegal awareness among patients, a minimum standard of care that reduces hazard exposure and transmission of infection has to be maintained while doing electrosurgery and laser procedures. Awareness and management strategies should be a part of the training curriculum for both doctors and the supportive health care providers. Smoke evacuators are a must for any dermatosurgical or laser clinic with easy, effective, and safe plume evacuation. The smoke evacuators available today are compact, portable, and easy to use. Although some systems may be expensive, they usually last for a long time with minimal maintenance.

In addition to smoke evacuation practices, high-filtration masks should also be worn by the surgical team as they offer superior protection compared to standard surgical masks. The smoke capture device should be held less than an inch away from the treatment site to achieve efficient evacuation. Standardized guidelines for surgical smoke evacuation should be laid down and followed strictly within the dermatology community with practices that are easy to implement and at the same time efficient in plume evacuation. A multidisciplinary approach with education of staff, good general ventilation, use of high-filtration masks, and a smoke evacuator is ideal. Hazard reduction practices that need to be implemented in a dermatologist's clinic are enumerated in Table 7.

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Conflicts of interest

There are no conflicts of interest.

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Figures and Tables

Table 1

Risks of surgical smoke

1. Unpleasant and noxious odor
2. Burning and irritation in the eyes
3. Acute and chronic inhalational injury to the lungs
4. Mutagenic effects of chemicals
5. Risk of transmission of infection
6. Deposition of particulate matter in tubings and machines causing corrosion and damage
7. Visual problems for the doctor

Table 2

Comparison of electrosurgical and laser plume

	Electrosurgical plume	Laser plume
Source	Electrodessication, electrocoagulation, electrofulguration, radiofrequency ablation	Excimer, argon krypton, carbon dioxide, Erbium:YAG, ruby, diode, dyes, Nd:YAG, Alexandrite
Mean diameter	<0.1 μm	~0.3 μm
Plume produced on treating 1g of tissue	Equivalent to inhaling six unfiltered cigarettes	Equivalent to inhaling three unfiltered cigarettes
Chemicals found in significant concentrations	Benzene, ethyl benzene, xylene, styrene, carbon disulfide, and toluene	Acetonitrile, acrolein, ammonia, benzene, ethylene, and toluene

Table 3

Infectious hazards

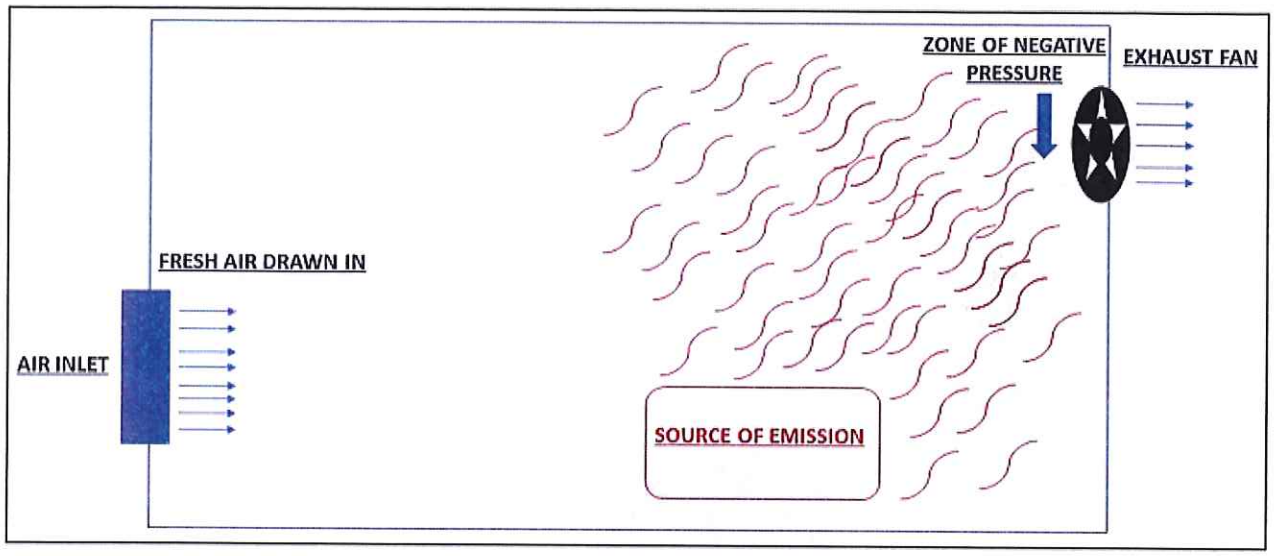
The following infectious particles have been detected in surgical plume	
Virus	Human papillomavirus
	HIV proviral DNA
Bacteria	Staphylococcus
	Corynebacterium
	Neisseria

Table 4

Noninfectious hazards

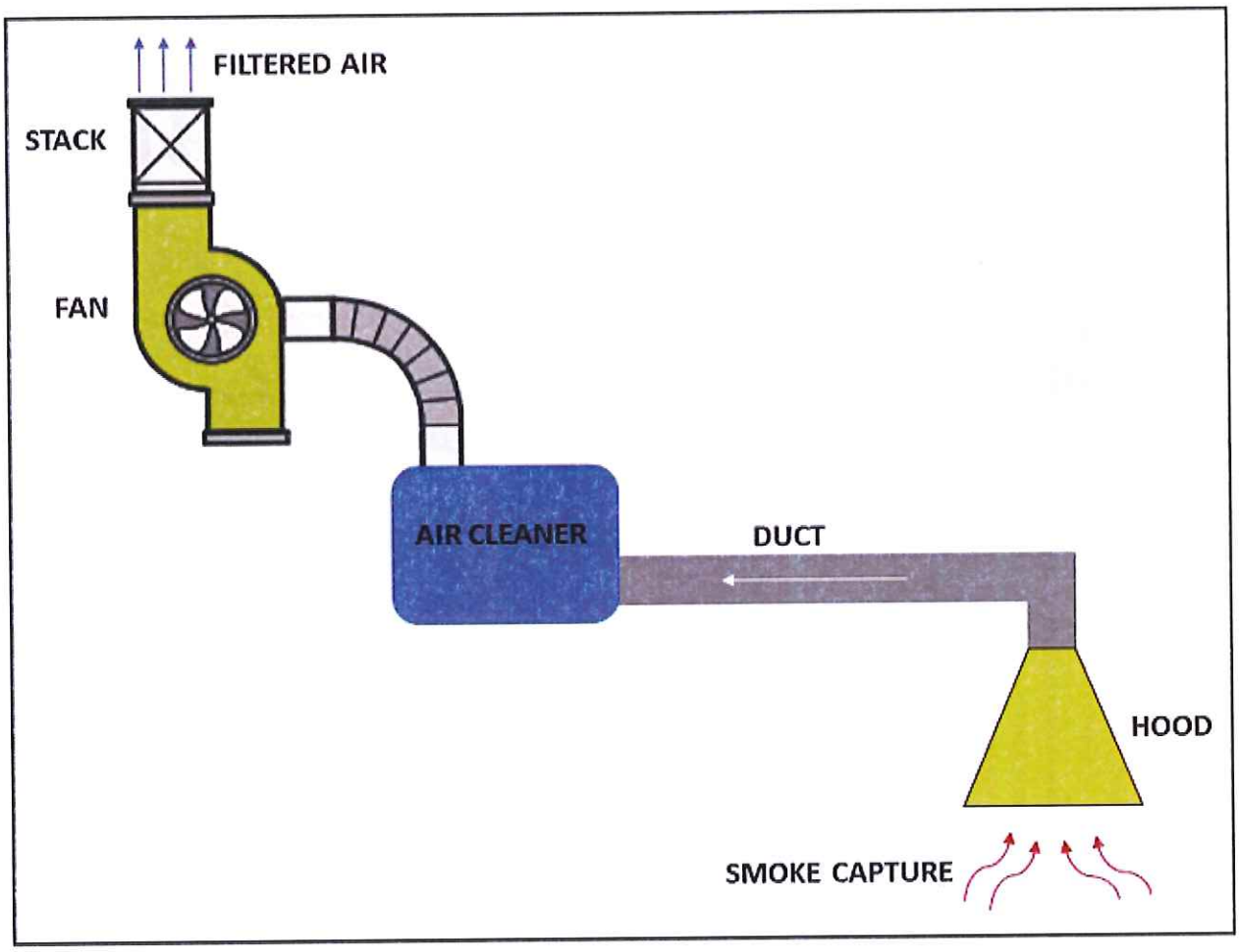
1. Ocular	Irritation, can hinder surgeon's view of the surgical site
2. Olfactory	Noxious odor
3. Respiratory	Rhinitis, asthma, bronchitis, alveolar congestion, interstitial pneumonia, emphysema
4. Carcinogenesis	Due to chronic exposure to chemicals
5. Cardiopulmonary disease	Due to chronic exposure
6. Others	Headache, nausea, vomiting, dizziness, weakness, light headedness

Figure 1



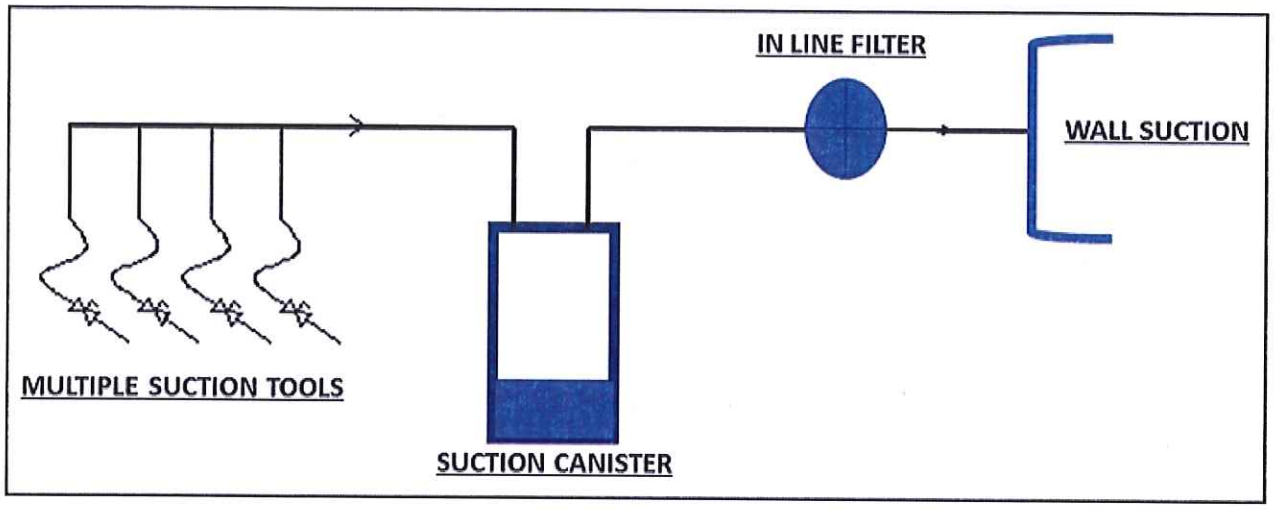
General exhaust ventilation via exhaust fan

Figure 2



Principle of local exhaust ventilation

Figure 3



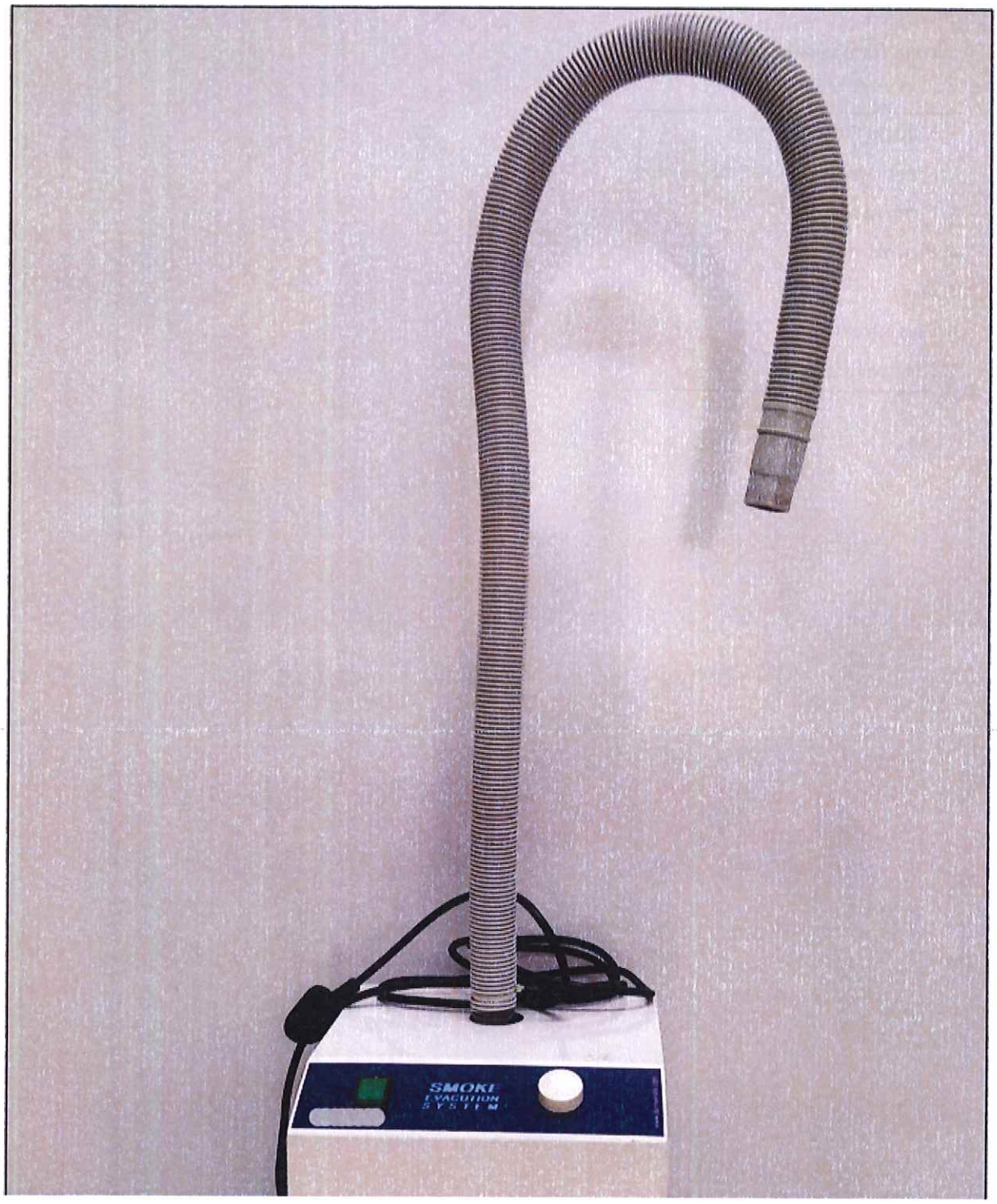
Schematic diagram of wall suction unit with an in-line filter

Table 5

Importance of a smoke evacuator

1. Captures the pollutants close to the source of emission
2. Prevents dispersion of particulate matter and contaminants in workplace air
3. Reduces unpleasant odor
4. Minimizes exposure of the health care professionals and the patient to contaminants
5. Keeps the surgical field clear
6. Prevents corrosion and damage to other equipment due to corrosive chemicals in surgical plume
7. Maintains a safe environment

Figure 4



Open in a separate window

The basic model of a smoke evacuator with an inlet, tubing, and suction unit

Table 6

Criteria for a good smoke evacuator

1. Efficient filtration system
2. Capture velocity of 30.5–45.7 m/min
3. Compact size
4. Portable
5. Quiet
6. Cost effective
7. Easy maintenance

Table 7

Hazard reduction practices to be implemented in dermatologist's clinic

1. Adequate education and training of doctors and supportive staff
2. Determine the level of smoke exposure by approximating the amount of plume generated during procedures
3. Maintain good general ventilation in the clinic to dilute contaminants in the air in the absence of a smoke evacuation system
4. Proper fitting high-filtration masks to be used by the surgical team during procedures
5. A smoke evacuator should be used while doing procedures that generate plume. For example, viral warts, epidermal nevi, laser ablation, and laser hair reduction
6. The smoke capture device should be held less than an inch away from the source of emission to ensure efficient plume evacuation
7. To follow national minimum standard guidelines of care for setting up a laser room or dermatosurgery theatre

JAMA Surgery | Review

Occupational Reproductive Hazards for Female Surgeons in the Operating Room
A Review

Matilda Anderson, MBBS, MPH; Rose H. Goldman, MD, MPH

IMPORTANCE Higher rates of infertility and pregnancy complications have been found for female surgeons compared with the general population. Several reproductive hazards are present in the operating room and may be associated with these findings. Hazards should be identified and controlled to minimize risks.

OBSERVATIONS Studies comparing surgeons with the general population show increased rates of infertility and pregnancy complications, including conditions affecting both mother and fetus, such as spontaneous abortion, preterm delivery, growth restriction, and congenital abnormalities. Attention has focused on older age and demanding working conditions of pregnant surgeons; however, there are reproductive hazards present in the operating room that might also be contributing. Relevant hazards include radiation, surgical smoke, working conditions, sharps injury, anesthetic gases, and intraoperative use of toxic agents. Published evidence is limited to retrospective studies. Robust data are often unavailable to guide specific dose-response relationships, making it difficult to quantify risk and create occupational safety guidelines. Nevertheless, regulatory agencies have set exposure limits for some agents, relying on limited evidence. Various workplace interventions have shown success in reducing exposure levels for many reproductive hazards and should be adopted by surgical workplaces.

CONCLUSIONS AND RELEVANCE Reproductive hazards exist in the operating room that may contribute to pregnancy complications and infertility in surgeons. Information and guidance should be given to female surgeons and trainees of reproductive age, and efforts should be made in the workplace to control exposures but not restrict female surgeons' activities unnecessarily.

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Female surgeons have been found to have high rates of adverse pregnancy outcomes and infertility.[1-3] A survey of 1021 US female surgeons across different specialties found an overall pregnancy complication rate of 35.3%, compared with 14.5% in the general population.[3] Other studies support this finding, with a complication rate of 25.3% identified in a survey of 163 female urologists.[2] High infertility rates in surgeons have also been described.[1,3,4] A total of 32% of respondents to the 2012 survey reported difficulty with fertility compared with 10.9% of the general population.[3]

These findings are increasingly significant with female representation in the surgical workforce rising. In the United Kingdom, women now compose 11.1% of consultant surgeons compared with 3% in 1991.[5] In the United States, 20.6% of general surgeons are women compared with 13.6% 10 years ago.[6,7] Female surgeons are having children at an older age: average age at delivery of their first child reported in the 2012 survey was 33 years, compared with 26 years in the general population.[3,8] Advancing maternal age is a risk factor for infertility and adverse pregnancy outcomes, but the extent of the role of age in complication rates in surgeons is difficult to determine. Although older than the comparison population, the female surgeons' average age at first delivery is younger than 35 years, which is traditionally considered the cutoff for advanced maternal age.[9] The association of occupational reproductive hazards with infertility and pregnancy complications in this population has not been adequately explored or defined. Operating room reproductive hazards are summarized in **Table 1**.

Observations

Radiation

Exposure to radiation in the operating room occurs via use of radioactive tracers and imaging techniques that aid surgical procedures. The use of intraoperative radiation is increasing, including development of hybrid operating rooms, which use fixed imaging, such as C-arms and computed tomography.[10] Many specialty surgeons also work and train in an angiography suite; currently, 50% to 75% of all vascular interventions require radiation.[11]

APPENDIX VI

Table 1. Operating Room Reproductive Hazards

Operating Room Hazard	Potential Adverse Reproductive Outcomes From Exposure
Radiation	Fetal death: estimated threshold dose of 50-100 mGy occurring at 0-2 wk[12,14,16] Congenital abnormalities and growth restriction: estimated threshold dose of 200-250 mGy occurring at 2-8 wk[12,14] Cognitive effects and microcephaly: estimated threshold dose of 60-310 mGy occurring at 8-25 wk[14] Increased risk of childhood cancer: no threshold dose but likely minimal risk at <10-20 mGy[14]
Surgical smoke	No studies directly investigating exposure of surgical smoke and reproductive outcomes; studies of smoke components have shown: Particulate matter: low birth weight and preterm labor[24] Toluene: congenital defects, cognitive impairment, infertility[27] Benzene: increased risk of childhood leukemia[25] 1,2-Dichlorethane: spontaneous abortion and infertility (animal studies only)[28]
Working conditions and physical demands	Working long hours (>40 h/wk): preterm delivery, spontaneous abortion, small for gestational age[31,32] Night shifts: preterm delivery and spontaneous abortion[31] High physical demands: possible risk of preterm delivery and small for gestational age[31]
Sharps injuries and blood borne pathogens	Risk of transmission of hepatitis B, hepatitis C and HIV
Waste anesthetic gases	Spontaneous abortion[48-50] Congenital abnormalities[48] Reduced fertility (nitrous oxide)[48]
HIPEC	No studies directly investigating operating room use of HIPEC and reproductive outcomes; spontaneous abortion, congenital abnormalities, low birth weight, and infertility observed in studies of occupational exposure to antineoplastic drugs[51,52]
Methyl methacrylate	No human studies; skeletal abnormalities and growth restriction in rats associated with very high exposure levels (maternally toxic levels)[53]

Abbreviation: HIPEC, hyperthermic intraperitoneal chemotherapy.

Toxic effects of radiation exposure on the developing fetus include prenatal death, growth restriction, congenital anomalies, cognitive effects, and risk of childhood cancer.[12] Threshold radiation effects (deterministic) occur over a dose threshold and result in cellular injury.[13] Stochastic effects of radiation are incremental, occurring in a dose-response function without a threshold, and are thought to be the mechanism of increased risk of cancers.[13] Data from animal studies, pregnant atomic bomb survivors, and pregnant women receiving radiotherapy have guided estimated dose-response rates.[14] Quantifying exposure and defining risk are complicated by the different units denoting radiation dose. A gray is the absorption of 1 J of energy (in radiation form) per kilogram of tissue. A sievert measures the equivalent dose, which relates the absorbed dose to the effective biological damage, weighted for the potency of the radiation and sensitivity of the exposed organ.[13] Current consensus in the literature is that fetal risks are negligible at a total radiation dose of less than 50 mGy (equivalent to 50 mSv when considering exposure to radiation) during pregnancy.[14,15] Zero to 2 weeks is the most sensitive time for fetal death from excessive radiation exposure, with the threshold dose estimated to be 50 to 100 mGy.[12,14,16] Congenital anomalies and growth restriction can occur at 200- to 250-mGy doses during 2 to 8 weeks of gestation.[14] Cognitive effects and microcephaly can occur from exposure during the 8- to 25-week period, with a suggested threshold dose of 60 to 310 mGy.[14] There is limited knowledge of future carcinogenesis risk as a result of in utero exposure to radiation. It is suggested that exposure to 10 to 20 mGy or higher may slightly increase risk, although minimally above the population incidence rate.[14]

The estimated average annual radiation dose per person in the United States is 6.2 mSv (background, medical, industrial, and consumer sources).[17] The sievert unit is used with this estimate because it encompasses different forms of radiation exposure. The International Commission on Radiological Protection recommends that after a worker declares her pregnancy, the occupational radiation dose should not exceed 1 mSv during the remainder of the pregnancy.[13] However, regulatory levels differ among agencies. The National Council on Radiation Protection and Measurements in the United States recommends a dose limit of 0.5 mSv per month once pregnancy is confirmed to ensure low exposure during particularly sensitive periods of gestation.[13] The US Environmental Protection Agency recommends a limit of 5 mSv for the entire gestational period.[13]

Studies examining radiation doses in surgeons and trainees show mixed results. A study of neurosurgical residents performing surgeries under radiologic guidance in the operating room found that the average cumulative dose over the 7-year training program was 12.15 mSv (1.73 mSv per year).[18] A US study examining radiation dose in interventional urologists and vascular surgeons found that the average monthly maternal dose was above recommended levels from measurements from over-lead apron dosimeters, but negligible from fetal monitors worn under lead gowns.[11] Fetal radiation monitors are used to demonstrate adherence to established limits but are not routinely used at every institution internationally. No studies identified in this review reported exposures above recommended levels at the abdominal level under a lead gown.

Sentinel lymph node biopsy procedures use radioactive tracers, such as technetium-99, for nodal identification. Factors associated with exposure include distance from injection site to the surgeon's abdomen and time between injection and surgery (reflecting decay time). A review of 11 studies examining radiation dose during breast sentinel lymph node biopsy suggested, as a conservative estimate, that performing less than 100 sentinel node procedures during a pregnancy would safely fall below a level of a 1-mSv dose to the fetus during the gestation period.[15]

Many studies note the poor understanding of radiation exposure and risk among health professionals.[10,13] Pregnant surgeons have been known to wear 2 gowns, which increases physical demand.[11] Lack of knowledge often surrounds decision-making by workers regarding radiation safety, causing anxiety and lack of participation in operating rooms that use radiologic procedures intraoperatively.[13] Provision of accurate information regarding radiation risks, available control measures, and the ability to moni-

tor radiation exposure will assist surgeons to make more informed decisions.

Surgical Smoke

The term *surgical smoke* refers to the products created by energy sources in the operating room, such as electrocautery. The content of the smoke plume includes water, gases containing chemical compounds (Box), particulate matter, cellular material, bacteria, and viruses.[19,22] The exact composition and amount of surgical smoke produced depends on the surgical device used and the tissue environment.[20] Higher emissions have been detected from cautery of solid organs or fatty tissue, for example, compared with muscle.[23] We found no studies specifically examining the effects of surgical smoke on reproductive outcomes. However, several components of surgical smoke are reproductive toxins and have been studied in other settings. Exposure to fine particulate matter from air pollution has been associated with low birth weight and preterm labor.[24] Benzene exposure in utero has been associated with increased risk of childhood leukemia in animal and human studies.[25,26] Toluene has been associated with congenital defects, cognitive impairment, and infertility.[27] Animal studies have shown that 1,2-dichlorethane exposure caused decreased fertility and increased risk of miscarriage.[28]

A few studies have measured smoke emissions in the operating room rather than in the laboratory. An investigation of fine and ultrafine (<100 nm) particle exposure during both open and laparoscopic cases found a high concentration at the breathing zone.[23] Intermittent peaks of up to greater than 100 000 per cm^3 were found, in contrast to average levels of 5000 per cm^3 found in homes or ambient areas.[23] A study of laparoscopic cases collected the smoke released from a laparoscopic trocar site after 30 minutes of operating and found the concentrations of benzene and 1,2-dichloroethane to be at unacceptable risk levels (greater than the Environmental Protection Agency excess cancer risk of 1 in 10 000).[21] Standard surgical masks provide a barrier but do not prevent exposure entirely as they cannot filter against particles smaller than 5 µm.[20] The N95 masks filter against particles larger than 0.3 µm and are recommended for high aerosol-generating procedures, but can be uncomfortable to wear.[29]

Many agencies, including the US Occupational Safety and Health Administration (OSHA), National Institute of Occupational Safety and Health (NIOSH), and the Association of Perioperative Registered Nurses have recommendations on minimizing exposure to surgical smoke in the operating room, including use of local exhaust ventilation (smoke evacuators over room suction only) and training of workers about surgical smoke and methods to minimize exposure. However, reluctance persists on the use of exhaust devices. A study conducted in the United States found that only 14% of operating room workers surveyed always used smoke evacuators. Contributing factors were the exhaust noise, obstruction of the operating space, and a lack of awareness of the hazards of surgical smoke.[30]

Working Conditions and Physical Demands

Working conditions commonly found in the surgical profession (including night shifts, long working hours, prolonged standing, and high physical workload) have been proposed to adversely affect fertility and pregnancy outcomes.[31] A meta-analysis reviewed the evidence and noted significant bias and confounding factors throughout the literature.[31] The authors selected studies with large numbers and pregnancy outcomes obtained from objective sources. The evidence base was strongest for increased risk of preterm delivery (PTD), with a pooled risk ratio of 1.23 (95% CI, 1.13-1.34) for women working more than 40 hours per week compared with those working less than 40 hours per week.[31] A small increased risk for PTD and small for gestational age may exist for higher physical demands, but this estimated risk is gradually decreasing with larger and better-designed studies.[31]

A recent systematic review that focused on nonstandard working hours found the quality of studies was low or very low according to their grading tool.[32] Nightshift work was associated with increased odds of PTD (odds ratio [OR], 1.21; 95% CI, 1.01-3.01) and miscarriage (OR, 1.23; 95% CI, 1.03-1.47), but not with preeclampsia or small for gestational age. Working more than 40 hours per week increased the risk of PTD (OR, 1.21; 95% CI, 1.11-1.33), miscarriage (OR, 1.38; 95% CI, 1.08-1.77), and birth weight lower than 2500 g (OR, 1.43; 95% CI, 1.11-1.84). This study did not further define the risk for levels beyond 40 hours. A large survey found no increased risk of PTD until residents worked more than 100 hours per week.[33] A Japanese study of 939 physicians found that working 71 hours or more per week was associated with a 4.2 times risk for PTD (95% CI, 1.9-9.2).[34] The Accreditation Council for Graduate Medical Education has set 80 hours per week as the maximum for residents (including surgical), with no adjustment for pregnancy. More research is needed, ideally prospective, to accurately evaluate outcomes.

Box. Chemicals Identified in Surgical Smoke[19-21]

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

Surgery can be a physically demanding specialty, with many studies demonstrating a risk of musculoskeletal pain and injury.[35,36] There is a paucity of data regarding lower back and pelvic pain in pregnant surgeons, particularly given prolonged standing and intraoperative physical demands. It is estimated that the prevalence of lower back and pelvic pain among pregnant women in the general population is between 36% and 62% and can severely limit activities of daily living.[37] More research is required to estimate the prevalence and circumstances of lower back and pelvic pain in pregnant surgeons to develop strategies to reduce workplace triggers.

Sharps Injuries and Blood-Borne Pathogens

Surgeons have the highest risk of sharps injury of all health care professionals owing to frequent performance of exposure-prone procedures.[38] Sharps injuries may occur in up to 15% of operations depending on the type of surgery.[39] A survey of 699 residents across the training years found that 99% had experienced a sharps injury by their final year of training.[40] The suture needle is the most common source of sharps injury in the operating room, with surgeon and first assistant being at highest risk of injury of operating room personnel.[39] Blood-borne pathogens of concern include hepatitis B virus, hepatitis C virus, and HIV. The probability of acquiring infection seroconversion from large-bore needlestick injury has been reported to be as high as 40% in workers not vaccinated against hepatitis B virus, 1.8% for hepatitis C virus, and 0.3% for HIV.[38] Because most operating room injuries are from suture needles, these figures may be different. If injury or inoculation were to occur during pregnancy, options for postexposure prophylaxis and treatment exist and should be provided if appropriate, with involvement of specialist infectious disease and obstetric clinicians.

The risk of exposure to hepatitis B virus has lowered significantly with adoption of preemployment hepatitis B vaccination policies. If an exposed pregnant worker was unvaccinated, postexposure prophylaxis with vaccination and administration of hepatitis B immune globulin would reduce the risk of hepatitis B virus infection by at least 75%.[41] Administration of vaccine and immune globulin to the newborn may confer more than 98% protection against maternofetal transmission.[42] There is no postexposure prophylaxis for hepatitis C virus exposure. The low seroconversion rate from needlestick injury as well as the low vertical transmission rate of 2% to 8% makes the risk of infection to the newborn relatively low.[43] Treatment for hepatitis C virus infection with interferon during pregnancy is contraindicated because of toxic effects. New-generation direct-acting antivirals are not yet recommended for use during pregnancy owing to lack of clinical data; however, early trials are underway.[44,45]

Pregnant surgeons should be offered postexposure prophylaxis for HIV exposure according to the guidelines as for any exposed health care worker, noting that the risk of transmission to the fetus is markedly increased during acute HIV infection in pregnancy and breastfeeding.[46] There is no evidence of toxic effects or birth defects from current treatment recommendations.[46] The suggested regimen from the US Public Health Service guidelines consists of tenofovir, emtricitabine, and raltegravir, which have pregnancy categories of B, B, and C, respectively, according to the US Food and Drug Administration.[46] Postexposure prophylaxis treatments change, so consultation with experts is advisable. Evidence-based strategies for prevention of sharps injury in the operating room recommended by professional and occupational health bodies include double gloving, use of blunt suture needles for closure of fascia and muscle layers, the use of hands-free or neutral zones for sharps transfers, and use of safety-engineered sharps devices.[47]

Anesthetic Gases

Inhaled anesthetic gases include 2 chemical classes: nitrous oxide and halogenated agents. Waste anesthetic gases (those that leak into the surrounding room during administration of an anesthetic) were first identified as an occupational reproductive hazard more than 50 years ago. Yet guidelines for exposure limits were developed predominately to prevent decreased cognitive function rather than to avoid adverse reproductive outcomes.[48] Issues to be addressed are to identify the types of adverse reproductive hazards associated with anesthetic gases and whether current guidelines are adequate.

A meta-analysis of studies investigating pregnancy outcomes with exposure to anesthetic gases demonstrated a statistically significant risk of spontaneous abortion among operating room nurses (risk ratio, 1.9; 95% CI, 1.72-2.09).[49] In 2000, the OSHA summarized available evidence and found that, despite study design limitations, the weight of evidence from both human and animal studies supported the association of increased risks of spontaneous abortion and congenital abnormalities with exposure to anesthetic gases and reduced fertility from exposure to high levels of nitrous oxide.[48]

Workplace exposure limits for waste anesthetic gases vary internationally.[50] The NIOSH has a recommended exposure limit for nitrous oxide of 25 ppm as a time-weighted average during the period of anesthetic administration.[54] This recommended exposure limit has not changed since initial publication in 1977, was based on limited studies, and the level was set to prevent decreased mental performance and dexterity rather than adverse reproductive outcomes.[48] The commonly quoted exposure limit for halogenated agents across guidelines is a ceiling concentration of 2 ppm over 1 hour. This level is from an NIOSH document from 1977 regarding halothane only, which predated introduction of other halogenated agents, such as isoflurane and sevoflurane.[55] In 2006, the NIOSH released a request for information to review data on the toxic effects of isoflurane, desflurane, and sevoflurane to establish a recommended exposure limit for these agents but so far has produced no update.[56]

The UK workplace daily exposure limit is 100 ppm for nitrous oxide, 10 ppm for halothane, and 50 ppm for isoflurane.[50,57] We found no information to explain the different limits. The lack of evidence in this area means that these recommended exposure limits give some guidance but cannot define the levels below which adverse reproductive effects definitively do not occur. However, a systematic review on general and reproductive toxic effects of volatile anesthetics noted that no studies have revealed adverse effects when levels were consistently kept below the recommended levels.[50]

Scavenging and ventilation systems have greatly improved control of exposure. Use of pressure and exhaust ventilation systems or laminar flow air conditioning with concurrent scavenging systems have been found to consistently keep air levels of nitrous oxide under 25 ppm and reduce concentrations of halogenated agents.[58,59] Although well-resourced countries, such as the United States, have these systems in place routinely, there are reports that some countries (eg, Poland and Iran) that lack these systems routinely exceed recommended limits.[58,60] Exposure above recom-

Table 2. Recommendations for Reducing Exposure to Reproductive Hazards in the Operating Room

Hazard	Recommendation
Radiation	Adhere to ALARA (as low as reasonably achievable radiation exposure) principles,[13] minimize beam on time,[13] mandate use of fitted personal protective garments/shielding (minimum of 0.25-to 0.50-mm lead-equivalent coverage),[13,70] maintain as great a distance as possible from the source of radiation,[13] women who have declared their pregnancy should wear fetal dosimeters (under gown at abdominal level) and be checked monthly,[70] counseling by a qualified medical expert regarding radiation exposure should be available[13]
Surgical smoke	Install and maintain an operating room ventilation system,[22] mandate use of smoke evacuators (rather than room suction only) with adequate capture velocity (31-46 m/min),[22] if room suction only used (not recommended), keep within 5 cm of surgical site with capture velocity 31-46 m/min,[19,22] minimize production of surgical smoke as much as possible (ie, consider other hemostatic measures),[22,71] use smoke evacuator systems during laparoscopic surgery rather than intermittent venting through laparoscopic ports,[21,71] consider use of high filtration mask advised for standard surgical procedures, use N95 respirators for aerosol-generating procedures[29]
Working conditions	Inform pregnant surgeons there may be some risk for adverse pregnancy outcomes in working night shifts, irregular hours, long working hours, and heavy physical load[72]; provide available alternative working conditions for pregnant surgeons that do not unfairly restrict duties
Sharps injuries	Abide by universal precaution principles; use double gloving, blunt-tip suture needles for closure of fascia and muscle; avoid hand-to-hand passing of sharps[47]; provide postexposure counseling with specialist input[46]; prescribe postexposure prophylaxis if suitable[46]
Anesthetic gases	Follow OSHA 2007 recommendations[73]; install and maintain operating room anesthetic gas-scavenging systems and ventilation systems[48,58,73]; ensure daily anesthetic apparatus checkout procedures and regular equipment maintenance[48,73]; use anesthetic techniques to avoid high-waste anesthetic gas levels (eg, avoiding high flow rates, minimize leaks)[48,73]; institute monitoring program of breathing zone atmospheric gas levels to ensure workplace compliance with RELs[48,73]
HIPEC	Advise pregnant workers that current safety reviews recommend against participation in HIPEC operating rooms[62,74]; advise workers actively pursuing pregnancy (female or male) that current safety reviews recommend against participation in HIPEC operating rooms[74]; adhere to NIOSH recommendations regarding the preparation, handling, equipment maintenance, and waste disposal of chemotherapy agents[52]; provide adequate training for hazard prevention given unfamiliarity with antineoplastic agents by operating room workers[59,74]; use triple gloving for surgeon in direct contact with chemotherapy agent and glove change every 30 min[63]
Methyl methacrylate	Install and maintain laminar flow operating room ventilation[75]; provide surgical hooded helmets for intraoperative use[52]; use vacuum cement mixing systems and local suction devices during preparation[16]

Abbreviations: HIPEC, hyperthermic intraperitoneal chemotherapy; NIOSH, National Institute of Occupational Safety and Health; OSHA, Occupational Safety and Health Administration; REL, recommended exposure limit.

mended levels has also been measured in recovery rooms, because patients exhale residual anesthetic gases where no scavenging systems are in place.[60,61]

Hyperthermic Intraperitoneal Chemotherapy

Cytoreductive surgery and hyperthermic intraperitoneal chemotherapy (HIPEC) is increasingly being used as a treatment modality for peritoneal carcinomatosis.[62] This technique has introduced chemotherapy agents into the operating room and brings new hazards, particularly for workers unfamiliar with safety regulations regarding their handling. Chemotherapy agents used in HIPEC (eg, mitomycin C and platinum-based compounds) have known carcinogenic, mutagenic, and reproductive toxic effects.[51] Exposure can occur through inhalation or skin contact. Studies in workplace settings other than the operating room have shown an association between handling of antineoplastic drugs and adverse reproductive outcomes, including an increased risk of congenital malformations, miscarriage, and infertility.[51,52]

Measurement of surface contamination is considered the best indicator of worker exposure to these agents.[51] The limited literature on this subject presents varying opinions regarding the degree of contamination from HIPEC in the operating room. One study found no breathing zone contamination during open-abdomen oxaliplatin HIPEC but detected heavy contamination of the operating table, floor, and surgeon's hands despite double gloving.[63] Studies and guidelines suggest that pregnant women and women wishing to become pregnant should avoid handling chemotherapy agents and be excluded from operating rooms conducting HIPEC owing to safety concerns.[51,62,64]

Methyl Methacrylate

Methyl methacrylate is a monomer of acrylic resin and commonly used in orthopedic and dental operating rooms. Exposure can be via the respiratory tract during mixing, implantation, and removal of methyl methacrylate cement. Concern was raised for reproductive toxic effects after skeletal abnormalities and growth restriction were shown in rat studies, although the effects occurred at high exposure levels that were generally maternally toxic.[53] To our knowledge, no further studies have defined a threshold for toxic effects in animals or humans.

The OSHA-permissible exposure limit of 100 ppm over an 8-hour workday is based on respiratory irritation rather than reproductive adverse effects.[53,65] One study measured methyl methacrylate exposure in a simulated environment via vapor monitoring stations in an operating room with ventilation according to NIOSH standards.[66] The investigators found that surgeons wearing a hooded helmet performing 4 total hip arthroplasties with vacuum mixing over an 8-hour period would experience a total exposure of 0.15 ppm.[66] The study also found less exposure when using hooded helmets vs standard surgical masks and using vacuum mixing systems compared with hand mixing.

Limitations

The literature in this area has several limitations. Studies on pregnancy outcomes are retrospective, rely on self-reported outcomes, and may have some degree of selection and recall bias. There are minimal studies reporting surgeons' outcomes compared with nonsurgical specialties. It is difficult to define clear dose-response relationships for each hazard and their toxic reproductive effects. Guidelines concerning safe exposure levels are usually based on nonreproductive outcomes and differ between occupational health organizations.

Conclusions

Occupational hazards exist in the operating room that may be factors in increased rates of infertility and adverse pregnancy outcomes for surgeons. It is important for the workplace and surgeons to understand what information is available. At a minimum, workplaces

need to comply with existing guidelines or standards, recognizing that these may not be protective for reproductive outcomes, and so that it may be wise to do more. Alternative work duties and/or conditions should be readily available. Priority should be given to controlling exposure rather than restricting surgeons' activity.

Measures must be taken to support women of childbearing age in the surgical workplace. Female surgeons perceive stigma regarding pregnancy, especially during training.[67,68] Most surgical training centers do not have programs or policies in place to protect pregnant surgeons, despite calls for implementation.[67,69] Conversely, some countries have strict workplace guidelines for pregnant workers: Germany's Maternity Protection Act limits surgeons operating from 21 weeks of gestation.[69] Without careful consideration of the evidence, policies such as these may act to unfairly discriminate rather than support pregnant surgeons. We have developed recommendations aimed to reduce exposures (**Table 2**) based on our review of the best evidence.

Given the limited data regarding operating room hazards and reproductive outcomes, as well as introduction of new operating room environmental exposures, more research is needed to define their reproductive effects, as well as effective and practical interventions to reduce exposure. In addition, prospective studies of women of reproductive age are needed to measure exposure levels and accurately record pregnancy outcomes.

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Review

Awareness of surgical smoke hazards and enhancement of surgical smoke prevention among the gynecologists

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Abstract

Surgical smoke is the gaseous by-product produced by heat generating devices in various surgical operations including laser conization and loop electrosurgical procedures that often are performed by gynecologists. Surgical smoke contains chemicals, blood and tissue particles, bacteria, and viruses, which has been shown to exhibit potential risks for surgeons, nurses, anesthesiologists, and technicians in the operation room due to long term exposure of smoke. In this review, we describe the detailed information of the components of surgical smoke. Moreover, we highlight the effects of surgical smoke on carcinogenesis, mutagenesis, and infection in gynecologists. Furthermore, we discussed how to prevent the surgical smoke via using high-filtration masks and smoke evacuation systems as well as legal guidelines for protection measures among the gynecologists.

Key words: Cervical cancer; Cervical intraepithelial neoplasia; Electrosurgery; Smoke; Gynecologist.

Introduction

Cervical cancer remains to be one of the leading causes of cancer-related death in women despite advances in screening, diagnosis, prevention, and treatment. An estimated 13,240 patients will be diagnosed with cervical cancer in the United States in 2018 and about 4,170 cases will die because of this deadly disease, corresponding to almost 11 deaths per day [1]. Therefore, to obtain the better treatment outcomes, the prevention is imperative via early detection of precancerous and high-grade cervical intraepithelial neoplasia (known as cervical dysplasia, CINII and CINIII), which is the potentially premalignant transformation and abnormal growth (dysplasia) of squamous cells on the surface of the cervix [2-4]. Emerging evidence has demonstrated that virus infection and multiple molecular signaling pathways were critically involved in cervical tumorigenesis. Studies have revealed that human papillomavirus (HPV) infection is associated with progression of CINII and CINIII, and invasive cancer. Especially, patients with infection of HPV strains 16 and 18 cause about 70% of CINII, CINIII, and cervical cancer [3, 5, 6]. Thus, HPV vaccine is useful for prevention of the cervical cancer.

The treatment of CIN is effective and safe [7, 8]. The cervix lesions need to be treated with an ablative approach or an excisional technique, which are dependent on the size and location of the lesion [9]. The ablative approaches have cryotherapy and thermal ablation, while excisional methods have large loop excision or cold knife conization. Currently, the treatment for CIN applies for laser and electrosurgical managements. Laser conization and electrosurgical procedures such as the loop electrosurgical excisional procedure (LEEP) have been considered as accurate techniques in cervical cancer prevention [9-11].

To date, using electrocautery and lasers by gynecologists in cervical cancer and ovarian cancer is frequent, especially LEEP treated for CINII and CINIII with HPV infection, which may cause a critical healthy problem due to gaseous byproducts or "surgical smoke" produced by these devices. Surgical smoke poses a wealth of potential risks to the gynecologists, including the direct physical injury,

mutagenicity and transmission of infectious diseases especially HPV. However, legal guidelines and standardized recommendations within the gynecologists have not yet been established. Thus, in the following sections, we will review the contents and potential risks of surgical smoke and offer some recommendations for gynecologists to minimize the hazards.

What is the surgical smoke?

Surgical smoke is the gaseous by-product produced when tissue is dissected or cauterized by heat generating devices such as lasers, electrosurgical units, ultrasonic devices, and high speed burrs, drills and saws. Among these devices, the most common sources are electrocautery ablation and laser ablation [12, 13]. During the surgical procedures, the heat of a diathermy causes the target cell membranes to rupture to its boiling point, and subsequently generates a plume of smoke containing mostly water vapor and then releases into the atmosphere of the operating room [13, 14]. At the same time, the intense heat created by chars protein and other organic matter within the cells causes thermal necrosis in the adjacent cells. The charring of cells also releases other harmful contaminants, such as carbonized cell fragments and gaseous hydrocarbons [15].

Surgical smoke, the encompassing term for a number of gaseous byproducts produced by energy-based surgical instruments, is also known as plume, aerosols, smoke, cautery smoke, diathermy plume and smoke plume [14, 16-18]. Most of these terms are often used interchangeably. However, the term "smoke", although it is not formally correct in all cases, is used to describe this surgically generated gaseous by-product [18].

The risks of surgical smoke

There are many disadvantages of surgical smoke, such as hindering the vision of the surgeon, producing an unpleasant odor, and releasing hazardous chemicals that include mutagens and carcinogens into the environment of operating room [19, 20]. A current study that was carried out in the operating rooms with 45 nurses and 36 doctors demonstrated that all of the 81 nurses and doctors exposed to surgical smoke experienced headaches, watery eyes, coughs, burning throats, nausea, bad odors absorbed in the hair, drowsiness, dizziness, sneezing and rhinitis [21]. In addition to the harmful chemicals, surgical smoke has been demonstrated to harbor contagious, viable malignant cells, and even to contain live bacteria and viruses, including HPV and human immunodeficiency virus [22-24], all of which may induce great damage to the persons in the operation rooms. For example, 80% smoke plumes were found to be positive for HPV from patients with HPV-positive CIN after LEEP treatment, suggesting that stringent control procedures could be required to protect gynecologist [23]. Each year, in America, a total of approximately 500,000 personnel including surgeons, nurses, anesthesiologists, and technicians were exposed to surgical smoke in the operating rooms, and these exposures were cumulative over their lifetimes [25]. Even though surgical smoke is not an immediate health hazard, operating room personnel should be aware of the potential long-term health risks.

The components of surgical smoke

Chemical compositions and hazards

Surgical smoke is made up of 95% water or steam and 5% cellular debris in the form of particulate material which is composed of chemicals, blood and tissue particles, viruses, and bacteria [17, 26]. As the studies revealed, the size of the particulate matter is decided by the device used and tissue type [26]. Electrocautery creates particles with the smallest mean aerodynamic size (0.07μm), whereas laser tissue ablation creates larger particles (0.31μm) [27, 28]. On the other hand, Karjalainen et al. [29] compared the deposition of particulate matter in ten different tissues containing skeletal muscle, liver, lung, bronchus, subcutaneous fat, renal pelvis, renal cortex, cerebral gray and white matter, and skin, all taken from the porcine tissues. The results showed that liver produced the highest number of particles, skeletal muscle and renal tissues produced a medium mass of particulate matter, while other tissues produced significantly less particulate mass, firmly suggesting the obvious differences in particle production of the surgical smoke depending on the electrocauterized tissue types [29].

There are mounting evidences suggesting that particles about 5 μm or larger are deposited on the walls of the nose, pharynx, trachea, and bronchus, while those smaller than 2 micrometers are deposited in the bronchioles and alveoli [26-28]. Besides, 77% of particles inside the plume are less than 1.1μm with a mean diameter of 0.07μm [30, 31], and a mean diameter of 0.22 μm to 0.056 μm are certainly in the inspirable range [17]. Therefore, smoke may induce acute and chronic inflammatory changes, including alveolar congestion, interstitial pneumonia, bronchiolitis, and emphysematous changes in the respiratory tract [18, 28]. Baggish et al. [32, 33] reported that laser-produced surgical smoke was harmful to the lungs of rat models. In the study, it was observed that the inhalation of surgical smoke caused

amount of damage from inflammatory interstitial pneumonia to extensive emphysema and that the changes proportionally increased with extended exposure. Moreover, Gates et al. [34] also reported that long-term exposure to surgical smoke, as measured by the duration of operating room employment, appears to increase the risk of chronic pulmonary conditions other than lung cancer, such as asthma or pneumonia. Another survey by Ball et al. [35] found that, compared to the general population, perioperative nurses displayed twice the incidence of some respiratory problems such as sinus problems, infections and bronchitis. Although the study did not discover any correlation between the inhalation of surgical smoke and respiratory problems, these findings could be a wake-up call for concern, as these conditions have been linked to inhaling surgical smoke.

In vitro investigation has identified many chemicals in the surgical smoke plume [12]. So far, researchers have identified more than 80 chemical compounds in the surgical smoke [36]. The most abundant chemicals in electrocautery smoke are hydrocarbons, nitriles, fatty acids and phenols. The plumes generated by laser tissue ablation include benzene, formaldehyde, acrolein and polycyclic aromatic hydrocarbons [28]. In addition, surgical smoke from adipose tissue produces more aldehydes than ketones whereas epidermal tissue ablation creates more toluene, ethyl benzene, and xylene [37]. Similar to this concept, another elegant study identified 9 main carcinogenic chemical compounds in surgical smoke form porcine tissues, butadiene, benzene and furfural was demonstrated to be obviously exceeded permissible exposure [38]. Further analyses revealed that as compared to muscle tissue, liver tissue of porcine contributed to higher concentrations of butadiene, benzene and furfural when cauterized in electrosurgery [38]. Chung et al. [20] collected 12 smoke samples from a continuous irrigation suction drainage system during TURP (transurethral resection of the prostate) and vaporization. This study showed that there were 16 main chemical constituents of surgical smoke including propylene, allene, isobutylene, 1,3-butadiene, vinyl acetylene, mecaptomethane, ethyl acetylene, diacetylene, 1-pentene, ethyl alcohol, piperylene, propenylacetylene, 1,4-pentadiene, cyclopentadiene, acrylonitrile and butyrolactone. Moreover, a recent study conducted by Sisler et al. [39] collected 36 surgical smoke samples by using an electrocautery surgical device to cut human breast tissues and characterized the particles from plumes. They detected 17 different volatile organic compounds in all the 36 surgical smoke samples, and high concentrations of acetaldehyde, ethanol and isopropyl alcohol were detected in every sample predominantly.

Acrylonitrile, is a colorless and volatile chemical that is able to be absorbed through the skin and lungs and exerts its toxicity by liberating cyanide [27]. The exposure levels of operating room personnel to acrylonitrile have been demonstrated to be 1.0–1.6 parts per million (ppm) [40]. Short-term exposure to acrylonitrile can cause eye irritation, nausea, vomiting, headache, sneezing, weakness and lightheadedness, whereas long-term exposure causes cancers in laboratory animals and has linked to higher incidences of cancer in humans. Repeated or prolonged exposure of the skin to acrylonitrile may produce irritation and dermatitis [28].

Hydrogen cyanide, which is liberated by acrylonitrile, is also a toxic colorless gas that can be absorbed into the lungs through the skin and the gastrointestinal tract [17]. Excessive exposure to hydrogen cyanide can cause cardiac arrhythmias, dyspnea, coma and even death, while chronic low level exposure may result in neurological effects such us headache, vertigo, nausea, and vomiting [15, 27]. Therefore, the United States Department of Health and Human Services has set the short-term exposure limit of hydrogen cyanide at 10 ppm [40].

Benzene has been detected at high levels (71 $\mu g/m^3$) near the electrocautery pencil during colorectal surgery and in the ambient air of the operating room (0.5–7.4 mg/m^3) [39]. In epidemiological study, clinical and laboratory data linked benzene exposure to aplastic anemia, acute leukemia, and bone marrow abnormalities [25-27, 42]. As stated by Occupational and Safety Health Administration (OSHA) [26], the short-term effects of benzene include headache, dizziness, nausea, and irritation of the eyes, nose, and respiratory tracts. National Institute of Occupational Safety and Health (NIOSH) recommended that exposure limit of benzene is 0.1 mg/m^3 and the OSHA limit of benzene is 0.2 mg/m^3.

Carcinogens in surgical smoke

Among these chemical compounds existing in surgical plume, acetaldehyde, acrolein, acrylonitrile, benzene, cyclohexanone, formaldehyde, furfural, polyaromatic hydrocarbons, styrene, toluene and xylene have been classified as carcinogens by the IARC (International Agency for Research on Cancer) [43]. 1,3-butadiene, vinyl acetylene and acrylonitrile have been demonstrated to be very toxic and carcinogenic further [20]. One study by Oganesyan et al. [44] used a well-established method to collect the smoke during active electrosurgery placed at 16 to 18

inches above the cautery point. The results showed the high concentrations of known carcinogens in surgical smoke such as benzene, butadiene, and acetonitrile. In addition, butadiene and benzene showed 17- and 10-fold higher concentration than second-hand smoking, respectively, which have been reported to cause acute or delayed toxicity and have potential carcinogenic effects on humans.

Laboratory and animal studies have demonstrated that smoke generated during laser and electrocautery surgery causes acute or delayed carcinogenic effects on humans. Even though there is no direct evidence to show that surgical smoke is carcinogenic to humans, there are persistent concerns.

Mutagenic potential of surgical smoke

As well as chemical components, the mutagenicity and cytotoxicity were of greatest concern to users of lasers, electrosurgery, and powered surgical instruments. Tomita and colleagues collected the electrosurgery smoke particles generated from mucous membrane of the canine tongue irradiated with a CO_2 laser, and found that condensates of surgical smoke have mutagenicity on TA98 in the presence of S9 mix, and His^+ revertants were induced with an increased dose of the condensates [45]. This result demonstrated the mutagenicity of a TA98 strain of Salmonella. Moreover, the authors quantified the mutagenic effect created by thermal destruction of 1 g of tissue was equivalent to that of three to six cigarettes respectively. Then, Gatti et al. [46] used the standard Salmonella microsomal test, an established technique for evaluating the mutagenicity of a substance, to assess the mutagenic potential of the electrocautery-derived smoke created during the reduction mammoplazy, and found the mutagenicity of smoke to a TA98 strain of Salmonella. In a subsequent laboratory study with porcine liver tissue repeatedly cutting by electro-surgical hook knife, authors collected the plumes and observed that the clonogenicity of the MCF-7 human breast carcinoma cells decreased about 30% when exposed to this plumes, suggesting the cytotoxicity of electro-surgical smoke [47, 48]. Additionally, an in vitro experiment has discovered that surgical smoke from human breast tissues via electrocautery surgical device induced cytotoxicity in human small airway epithelial cells and mouse macrophages [39], implying that surgical smoke may be an occupational hazard to healthcare workers. It was not determined in either study whether the plumes actually posed a serious health risk to perioperative personnel, but more attention should be paid for surgeon to safe levels of ambient mutagens.

Biological components of surgical smoke

Viable malignant cells

In addition to the various chemical compositions, surgical smoke also contains transmissible, viable malignant cells. As early as 1999, Fletcher et al. [24] cauterized pellets of B16-F0 mouse melanoma cells to collect plums and assessed cell viability by the way of the trypan blue assay and the tetrazolium viability assay, which showed that viable melanoma cells were present in the culture wells. These results demonstrated that plumes of electrocautery contained malignant cells which was viable and may explain the appearance of port-site metastases that were remoted from the surgical dissection or never in direct contact with the tumor. Another study also assessed the ability of surgical smoke to spread aerosolize malignant cells by the way of collecting thirty-five patients undergoing elective laparoscopy. As a result, aerosolized mesothelial cells were identified only in two patients, but one patient who displayed cellular aerosolization developed a port-site recurrence after following-up 2 to 7 months [49]. In the same year, other researchers collected surgical plume with Transwell membrane from various tumour cell lines (NCI-H292, FaDu, KB, AGS, ARO) cauterized by electrocautery, radiofrequency ablation and ultrasonic scalpels. These experiments demonstrated that it was only from the ultrasonic scalpel, but not from the electrosurgical unit or radiofrequency ablation device that viable cells were identified in all 25 smoke samples retrieved from a distance of 5 cm [50]. However, no more study has demonstrated the transmission of cancer cells to operation room personnel during electrosurgery [31].

Viable bacteria

A study by Schultz et al. [51] has demonstrated the extent of viable bacteria present in surgical plume with an experimental model of porcine tissue embedded with Serratia marcescens, which transmitted directly to operation room personnel. The researchers concluded that it was the blended current electrosurgery rather than pure coagulation electrosurgery that transmitted bacteria to nearby or adjacent sites.

Virus and its infection in gynecologist

HPV was detected in surgical smoke

The first insights into the infection of surgical smoke were those numerous animal and human studies about the viruses in the smoke to date. Several articles stated that HPV was not found in the plume, and others demonstrated that the risk of HPV contamination was low or impossible for the operation room staff [52, 53]. Weyandt at el. [52]

collected petri dishes placed in 1 and 2 m distance to the treatment weld and swabs from the glasses and nasolabial folds of the operating physician to assess the generation of aerosols containing HPV DNA during treatment of genital warts with multilayer argon plasma coagulation and with CO_2 laser ablation. They confirmed that HPV types of genital warts were not found in any of the petri dishes and swabs obtained during this treatment. Despite of the ability to transmit HPV DNA in surgical plume, the risk of dispersal of HPV to surgeons and the development of clinically active infection appears to be low [53].

However, the risk of occupational human papillomavirus transmission from patient to medical personnel during laser vaporization procedures remains controversial. As early as 1988, in order to analyze the viral DNA content in the vapor produced by the carbon dioxide laser during the vaporization of papillomavirus-infected verrucae, Garden et al. [54] used two models for evaluation: an in vitro cutaneous bovine fibropapilloma and an in vivo human plantar or mosaic verruca model, both of which demonstrated that intact viral DNA was in the plume collected during carbon dioxide laser therapy of papilloma virus-infected verrucae. Next year, Sawchuk et al. [55] also used a bioassay to demonstrate the presence of human papillomavirus DNA in surgical smoke derived from human plantar warts treated with carbon dioxide laser and electrocoagulation. In a subsequent study, Garden and colleagues went on to collect the laser plume from bovine papillomavirus–induced cutaneous fibropapillomas and then reinoculated onto the skin of calves. The results revealed that substantial amounts of bovine papillomavirus DNA were present in all of the laser plume samples and tumors developed in all of 3 calves in sites of control bovine papillomavirus (BPV) concentrate inoculums were infected with the same virus type, confirming that bovine papillomavirus isolated from carbon dioxide laser plume did induce lesions in healthy animals [56]. Later, many studies have demonstrated the presence of HPV in the plume. Sood et al. [23] conducted a study of 49 patients with evidence of CIN undergoing loop electrosurgical excision procedures. In the study, 39 plume samples were reported to be positive for HPV, with 16/18 most, which showed that the plume of smoke generated by LEEP had HPV DNA. Furthermore, according to a study including patient tissue samples from the urethral warts (n = 5), laryngeal papilloma (n = 5) which were all found positive for HPV, and the surgical gloves (n = 20) used by the employees such as the physicians and nurses. The results showed that all samples obtained from the surgical gloves tested positive for HPV after urethral warts procedures, and in one of the five surgeons and in three of the five nurse tested HPV positive after the treatment of laryngeal papilloma, respectively. Interestingly, all HPV genotypes presented were identical to the HPV of corresponding patient tissue specimens [57]. A relatively recent study evaluated HPV subtypes between the resected cones of LEEPs and the surgical plume resulting from LEEPs of high-grade squamous intraepithelial lesion of the cervix uteri and surprisingly found that these plumes contained high-risk HPV which was consistent with HPV subtypes identified in the resected cones. The further investigations of contamination with surgical plume are necessary for evaluation of potential hazards to be involved in gynecologists [58].

The infection of HPV found in gynecologist due to surgical smoke

Although the possibility of disease transmission through surgical smoke exists in humans, actual documented cases of pathogen transmission are rare. Four cases have essentially been proven. A 44-year-old gynecological laser surgeon, who had no respiratory diseases and was healthy, developed laryngeal papillomatosis and infected with HPV types 6 and 11 after treating patients with anogenital condylomata known to harbor the same viral types [59]. In Germany, a 28-year-old gynecological operating room nurse, who assisted repeatedly in electrosurgical and laser surgery in excisions of anogenital condylomas, developed a recurrent and histologically proven laryngeal papillomatosis. The expert opinion of a virological institute confirmed a high probability of correlation between the occupational exposure and the laryngeal papillomatosis [60]. A 53-year-old male gynecologist who have performed laser ablations and LEEP on greater than 3000 dysplastic cervical and vulvar lesions over 20 years of practice, presented with HPV 16 positive tonsillar squamous cell carcinoma. However, he had no identifiable risk factors other than long term occupational exposure to laser plumes. Another patient was a 62-year-old male gynecologist with a 30 year history of laser ablation and LEEP, having very few other risk factors for oropharyngeal cancer or HPV infection, subsequently developed HPV 16 positive base of tongue cancer [61]. Due to that HPV could induce inflammation and carcinoma, protective measures should be instituted for all healthcare personnel, particularly gynecological surgeons [62].

Other virus in surgical smoke

In addition to HPV, human immunodeficiency virus (HIV) is also receiving a lot of attention because

of its increasingly prevalence in the general population. Baggish et al. [22] conducted a research in which HIV proviral DNA was captured in the inner lumen of smoke evacuation tubing after in vitro laser vaporization of cultured HIV cells. This study has clearly shown that HIV was present in the laser smoke. Furthermore, Taravella et al. [63] found that infectious polio virus could be propagated in the plume collected from oral polio virus infected fibroblasts by means of an excimer laser. The evidence of a recent study revealed that hepatitis B virus (HBV) was present in surgical smoke. Kwak et al. [64] collected surgical smoke from 11 patients undergoing laparoscopic or robotic surgery. In sequence of HBV gene amplification and DNA sequencing, the authors found that HBV was detected in 10 of the 11 samples of surgical smoke.

Protective measures for gynecologist

Mask: an effective protector

After completing a search of the literature, all articles in this literature synthesis identified personal respiratory protection to prevent surgical smoke inhalation injury, such as a basic surgical mask, high-filtration mask, or an N95 respirator [65]. Surgical masks, in general, providing more than 90% protection for the patient and the operating room staff from exposure to surgical smoke, have been in use for more than a century [66]. Today, the focus of protection has shifted to how surgical masks can be used as a safeguard for the surgical staff from surgical smoke.

In one report of Sawchuk et al. [55], the authors conducted repeat experiments analyzed by dot-blot hybridization to identify whether placing a surgical mask in the vapor path could inhibit the papillomavirus in surgical plume. The results showed that no viral DNA was detected from vapor after placing a mask and abundant viral DNA was extracted in this mask, which strongly suggested that the potential risk of surgical smoke inhalation might be markedly reduced by wearing a surgical mask. Lewin et al. [26] also suggested that high-filtration masks should be used to prevent exposure in surgical smoke. However, the conclusion of the research by Oberg et al. [67] indicated that none of these surgical masks exhibited adequate filter performance can be considered respiratory protection devices. In this research, filtration performance was evaluated by means of monodisperse latex sphere and sodium chloride aerosols, and facial fit of surgical smoke was evaluated by qualitative and quantitative fit tests. As a result, all 9 masks exhibited a wide range of particle penetration both in latex sphere challenge tests (0%-84%) and sodium chloride challenge tests (4%-90%), respectively. Another assay described that live, infectious virus was extracted from the plumes behind all surgical masks tested, suggesting that influenza virus surviving in aerosol particles could be able to bypass or penetrate a surgical mask [68]. Besides, to be effective, respirator filtering materials must allow only minimal penetration of the contaminant and provide an airtight faceseal or positive pressure inside the facepiece. However, traditional surgical masks fulfill neither of these requirements. Their vulnerability of penetration demonstrated that surgical masks offered only partial protection because they filtered out particulates only as small as 5μm in diameter, by the way when sizes smaller than 5 μm, these particles were not filtered by surgical masks and might be inhaled by personnel in the operation room [31]. In addition, even high-filtration masks also referred to as laser masks, whose filter particles are about 0.1 micrometers in size [65, 69]. Actually, the particulate size of the particles in the smoke has been documented to be much smaller than 5μm particulate diameter that standard surgical masks could filter [17]. Bacteria can be as large as 30μm or smaller as 0.3 μm, and viruses are smaller and can range in size from 0.01μm to 0.3 μm. Besides, it has been reported that small particles less than 1.1 μm in diameter constitute 77% of the particulate matter found in surgical plume [69]. As a result, most surgical masks do not have adequate filtering or fitting attributes to provide respiratory protection for wearers.

Some current-model surgical masks such as Health Care Particulate Respirators categorized into N, R and P classes have greater filtering and face seal capabilities, and the most commonly used are N95 and other NIOSH-approved respirators [70]. Emerging evidence has illustrated the high efficiency particulate air (HEPA) filters are capable to arrest fine particles effectively, such as N95 respirator masks [71], which have the filter efficiency over 95% when challenged with 0.3 μm aerosols. Although no guidelines on the use of respirators for surgical procedures, it seems that respirators that are at least N95 grade provide the best protection against surgical smoke produced during the use of electrocautery, lasers, or ultrasonic scalpels. In the study of Edwards et al. [72], suggested that the key respiratory protection was the use of N95 and other NIOSH-approved respirators, because it was the only respiratory protection choice proven effective for personnel protection. Another research by Gao et al. [73] calculated the total protection factor to measure the performance of common surgical masks, N95 and N100 which were exposed to the surgical smoke

collected from surgical dissections on animal tissue by standard electro-cautery device. The results of this study revealed that the total protection factor of common surgical masks was close to 1 which provided minimal protection against surgical smoke, while the total protection factor of N95 surgical mask respirator was 208–263 and N100 filtering face piece respirator was 1,089–2,199, which could offer a higher level of protection. Notably, an elegant study compared the filtration efficiency of airborne bacteria between N95 respirator and disposable surgical mask, as a result, the filtration efficiency of N95 and disposable surgical mask were 99.93% and 91.53%, respectively, demonstrating the significant difference between the two masks [74]. Consistent with these findings were data showing that N95 respirators provided more protection in case of clinical respiratory illness and laboratory-confirmed bacterial, suggesting the effective use of respiratory protection for healthcare workers [75].

On the contrary, some researchers found that it was very difficult to breathe with an N95 mask because CO_2 levels elevated significantly, and it was easy to have some subjective symptoms, the complaints of headache, lightheadedness, and difficulty in communication [76]. Compared to nurses with lower body mass indexes, nurses with a higher body mass indexes had even more negative effects on some physiologic measures such as lower O_2 levels and higher heart rate, and worse subjective symptoms such as higher perceived exertion, shortness of breath, thermal discomfort, headaches, lightheadedness, and visual challenges [76].

Other useful measures for gynecologist

It is clear that masks especially N95 are important but not sufficient. Nowadays, protection measure with activated carbon fiber is increasingly acknowledged [71]. The combination of HEPA filters with activated carbon is commonly called "high efficiency gas adsorption" (HEGA) filters, which successfully prevent surgeons from volatile organic compounds and chemical vapors in surgical smoke [77]. The mask contains an activated carbon layer may provide the surgeon with additional protection [78]. Remarkably, a recent study has demonstrated that the risk of surgical smoke exposure during laparoscopic surgery could be reduced by activated carbon fiber filters [79]. Eighteen chemical components were discovered in the sample collected 20 min after the electrocautery device used. However, When using the activated carbon fiber filter, known carcinogens including 1,2-dichloroethane, benzene, and ethylbenzene were dramatically reduced by more than 85% and the risk was extremely eliminated, implying that operating room personnel should pay attention to the risk from surgical smoke and minimize this risk by using activated carbon fiber filter [79]. However, these activated carbon fibers have not been demonstrated in clinical practice, which deserve further investigation before a formal recommendation in gynecology and other surgeons.

In addition, another important precaution is proper and diligent use of a smoke evacuation system with a high efficiency filter. Smoke evacuation has been identified as a feasible and potentially useful way to reduce the surgical smoke [80]. Smoke evacuation is able to capture the smoke generated at the surgical site and remove it to an area away from the surgical team where it can be filtered, which have been shown to be the most effective in limiting exposure to the noxious odor and potential health hazards of electrosurgical and laser plume [81, 82]. The unanimous consensus of all such recognized authorities that the primary measures for protecting people against surgical smoke are local exhaust ventilators, which is composed of wall suction with an in-line particulate filter and smoke evacuator. It filters 99.9995% of contaminants ranging 0.12 microns or larger in diameter [81]. Consistently, one experiment tested the efficiency of portable smoke evacuation systems and found these filtration reduced surgical smoke up to 99%, however, this accompanied by high sound level, which exceeded recommended threshold limits [83]. Controversially, accumulated evidence has demonstrated the poor efficiency for smoke evacuation system in eliminating volatile organic compounds. One experimental study found that some chemical compounds such as acetaldehyde, acetone, acetonitrile, benzene, hexane, styrene and toluene could be detected but at lower concentrations less than the recommended exposure limits when local exhaust ventilation system is in place [84]. Besides, another group illustrated smoke evacuation system was unable to reduce some chemical compounds containing butadiene and benzene below the permissible exposure limits [38]. Despite recommendations from various professional organizations advocating the use of local exhaust ventilators and respiratory precautions, these measures are not being widely used because of its noise, cost, lack of equipment or repair parts, physician resistance, staff complacency, large and unwieldy local exhaust ventilators devices, and extra personal accommodating devices [72, 76, 85]. A recent web-based survey by Steege et al. [85] examined current surgical smoke practices of local exhaust ventilators and personal protective equipment which include respiratory protection approved by NIOSH. There were 4533 respondents to the survey, 56% were

nurses and 21% were anesthesiologists, the rest were technologists and surgical assistants. The researchers found that only 14% of respondents reported that local exhaust ventilators were always used during the procedures of electrosurgery, and fewer than half (47%) of the facilities used by survey respondents for most laser procedures. Of particular interest to gynecologists, 49% and 44% of survey respondents reported that they never had training on the hazards of surgical smoke in laser surgery and electro-surgery, respectively. Many studies demonstrated that better or more adherence of education was needed to raise awareness of potential hazards in surgical smoke and to awaken consciousness of a clear lack of health care personal protective measures, which might be served as a foundation to help inform safety guidelines in electrosurgery for formal gynecologist and obstetrician residents [86, 87]. A team of perioperative nurses and surgeons quantified smoke-evacuator use, assessed staff members' knowledge and presented a multimodal education program in order to improve compliance with policies and procedures for surgical smoke management in the operation room. As a result of a posteducation, this survey showed a 14.6% increase in surgical smoke-evacuation use which obviously revealed significant improvement in staff members' awareness about reducing surgical smoke in the operation room and helping patients, staff members, and the surgical team to ensure a safe environment [88].

Additionally, disposable smoke evacuation hose is one of the most previous ways used in electrosurgery to reduce surgical smoke [89]. Elimination of surgical smoke via a disposable built-in-filter trocar has been identified as a simple and effective way to reduce chemical compounds such as benzene, toluene, butyraldehyde, ethylbenzene, xylene, styrene, formaldehyde, and propionaldehyde, to some extent [90].

Besides, general room ventilation using a central plume evacuation system connected to several operating suites was also insufficient to effectively capture smoke generated at the surgical site [91]. These central evacuation systems removed the smoke directly to a remote site without using filters, and the captured device connected through tubing to a control panel that controlled the flow rate [81].

In spite of these protections, the existing problems on protections are obvious. On one hand, the outpatient department where most gynecological procedures of treating CIN are performed and operation room have a paucity of protective structures to protect gynecologists, our staff and our patients, there being neither any smoke evacuation system, filter, wall suction, nor a protocol regarding protection against surgical smoke [21]. On the other hand, most surgeons, perioperative personnel, and health care organizations lack a general knowledge regarding the potential health risks associated with exposure to surgical smoke and underuse of equipments that may provide effective protection because of inconvenience and expense [76, 87, 92]. Many surveys revealed that effective engineering controls, such as local exhaust ventilation procedures, were used by fewer than half of the facilities represented by survey respondents for most laser procedures and in very few facilities for most electrosurgery, electrocautery, or diathermy procedures [17, 65]. However, the organisations responsible for protecting the health of the workers in different countries have still not issued formal guidelines for the treatment and removal of the surgical smoke generated in both open and laparoscopic procedures. As gynecologists, we must realize that our decision of rejecting protective measures against surgical smoke will inevitably put not only ourselves but also our staff at risk. Therefore, what we also need is further training and reinforcement of universal precautions to reduce occupational exposures.

Conclusion and perspective

It is obvious that surgical smoke is dangerous to gynecologists who perform procedures using electrocautery and other heating process to treat CIN. Electrocautery creating particles are small enough to be inhaled through a surgical mask and deposited on the walls bronchioles and alveoli causing pulmonary diseases (List in Figure 1). Several particles contain chemical compounds known as carcinogens and biological substances considered mutagenic and possibly infectious, including malignant cells and viruses (List in Table 1). Further research should be encouraged to quantify the exposure of gynecologists to surgical smoke in the outpatient department. A number of areas not only require more investigation and research to demonstrate the harmful effects of surgical smoke and analyze the contents of the smoke, but also need long-term studies on exposure limits. In spite of doubting about the harmful effects of exposure to surgical smoke, caution should be applied and preventive measures within should be carried. Many guidelines indicate that the most important protective measure against surgical smoke is consistent and correct use of smoke evacuation and surgical mask. But these measures are not consistently implemented, nor are they legally mandated. Therefore, firstly, the diligent use of high-filtration masks in addition to smoke evacuation systems to gynecologists performing surgery is required.

Secondly, increased knowledge and training of the individual to enhance awareness of health care workers about the hazards of the surgical smoke is recommended. Thirdly, it should have positive perceptions about the attributes of smoke evacuation recommendations and ease of understanding and implementing smoke evacuation system. Lastly, these measures should be consistently implemented and legally mandated soon. Altogether, gynecologists should recognize the danger of surgical plume and request all necessary measures to protect both operating room staff and patients.

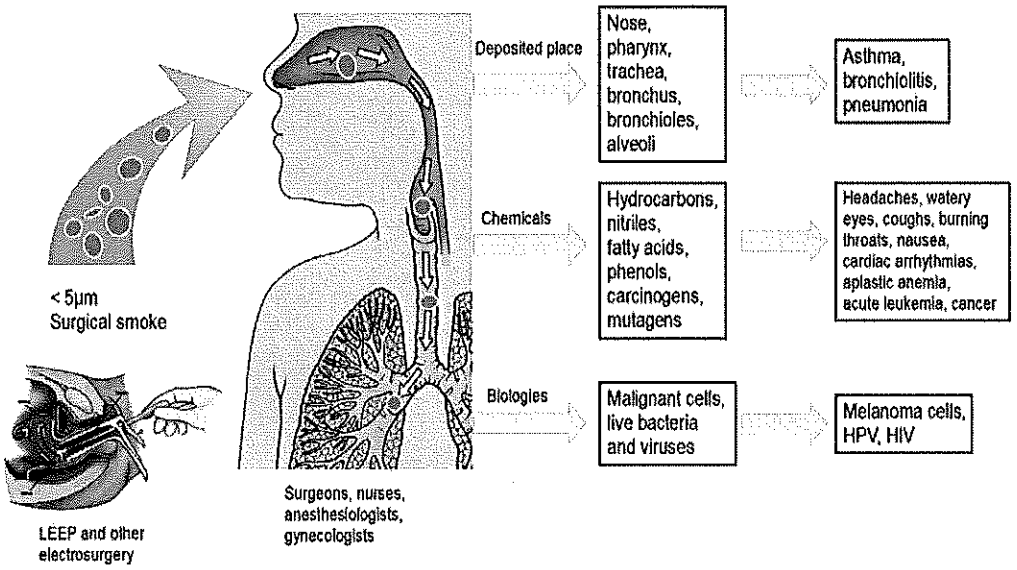

Figure 1: The hazards of surgical smoke produced by electrosurgical procedures to gynecologists. Surgical smoke produced by electrocautery contained particles small enough to be inhaled and deposited on the respiratory tract causing pulmonary diseases. Surgical smoke also poses chemical and biological components causing potential risks for healthcare workers.

Table 1: The various components of surgical smoke produced by electrosurgical procedures

Year	Surgery type or tissues	Energy device	Components	Ref.
Chemical components of surgical smoke				
1998	porcine liver	High-frequency electrocoagulation	2,3-dihydro indene, 3-butenenitrile, pyrrole, 2-nethyl propanol, 2-methyl furan2,5-dimethyl furan, 1 decene, benzonitrile, 6-methyl indole 3-methyl butenal, Methyl pyrazine, 1 undecene, ethynyl benzene, 2-propylene nitrile, indole, furfural, hexadecanoic acid, ethyl benzene, toluene, benzaldehyde, 4-methyl phenol	[93]
2007	Verrucae, pilonidal sinuses, abdominal procedures	diathermy	nalkanes, n-alkenes and aldehydes as well as toluene, ethyl benzene and xylene	[37]
2007	abdominal surgery	unipolar diathermy	hydrogen cyanide, acetylene, and 1,3-butadiene	[94]
2010	transurethral resection of the prostate	electrosurgical generator	propylene, allene, isobutylene, 1,3-butadiene, vinyl acetylene, mecaptomethane, ethyl acetylene, diacetylene, 1-pentene, ethyl alcohol, piperylene, propenylacetylene, 1,4-pentadiene, cyclopentadiene, acrylonitrile and butyrolactone	[20]
2012	laparoscopic intraabdominal surgery	Electrocautery or ultrasonic scalpels	benzene, ethylbenzene, styrene, toluene, heptene, and methylpropene	[13]
2014	laparoscopic cholecystectomy	electrosurgery	benzene, toluene, xylene, dioxins	[42]
2014	Dermatologic surgery	Monoterminal electrodessication and electrofulguration	1,3 butadiene, benzene, styrene, propylene, acetonitrile, vinyl acetate, n-heptane, 1,2-dichloroethane, chloromethane, hexanone, vinyl chloride	[44]
2016	laparoscopic or robotic surgery	electrosurgery	HBV	[64]
2016	Porcine gastric mucosal ablation	electrosurgical probe	toluene, 2-propyl-1-pentanol, perfluorooctan, propenoic acid, dimetyldodecane, 2-ethyl-1-hexanol, propylene glycol	[80]
2017	rectal cancer resection	electrocautery and ultrasonically activating scalpel	benzene, toluene, ethylbenzene, xylene, styrene, formaldehyde, acetaldehyde, propionaldehyde, butyraldehyde, isovaleraldehyde, and valeraldehyde	[90]
2018	human breast tissues	Electrocautery surgical device	acetaldehyde,α-pinene, benzene, chloroform, d-Limonene, ethanol, ethylbenzene, isopropyl alcohol, m,p-xylene, methyl, methylene, chloride, n-hexane, o-xylene, styrene, toluene	[39]
2018	porcine tissue	electrosurgery	acetylene, hydrogen cyanide, 1,3-butadiene,benzene,toluene, furfural, styrene, ethyl benzene and 1-decene	[38]
2018	porcine tissue	electrosurgery	produce different mass concentration and size distribution of smoke particles.	[29]
2018	transperitoneal laparoscopic nephrectomy	electrocautery device	ethanol, 1,2-dichloroethane, benzene, ethylbenzene, and styrene, acetone, 2-butanone, hexane, n-heptane, toluene, p-xylene, n-nonane, o-xylene, n-decane, n-undecane, n-hexadecane, n-tridecane, and n-tetradecane.	[79]
Mutagenicity and cytotoxicity of surgical smoke				
1981	mucous membrane of canine	carbon dioxide laser	mutagenicity of a TA98 strain of Salmonella	[45]

Year	Surgery type or tissues	Energy device	Components	Ref.
	tongue			
1992	reduction mammoplazy	electrocautery	mutagenicity of smoke to a TA98 strain of Salmonella	[46]
1998	porcine liver tissue	electro-surgical hook knife	cytotoxicity	[47]
2018	human breast tissues	Electrocautery surgical device	cytotoxicity	[39]
Viable malignant cells in surgical smoke				
1999	mouse melanoma cells	electrocautery	viable melanoma cells	[24]
2009	mouse melanoma cells.	electrosurgery	viable melanoma cells	[70]
2015	various tumour cell lines	electrocautery, radiofrequency ablation and ultrasonic scalpels	viable cells	[50]
Viable bacteria in surgical smoke				
2015	porcine tissue	electrosurgery	viable bacteria	[51]
Virus in surgical smoke				
1988	papilloma virus-infected verrucae	carbon dioxide laser	intact viral HPV DNA	[54]
1989	human plantar warts	carbon dioxide laser and electrocoagulation	HPV DNA	[55]
1991	cultured HIV cells	carbon dioxide laser	HIV proviral DNA	[22]
1994	CIN	LEEP	HPV DNA	[23]
1999	oral polio virus infected fibroblasts	excimer laser	infectious polio virus	[63]
2002	bovine papillomavirus-induced cutaneous fibropapillomas	carbon dioxide laser	bovine papillomavirus DNA	[56]
2011	genital warts	carbon dioxide laser	HPV DNA	[52]
2012	urethral warts, laryngeal papilloma	carbon dioxide laser	HPV positive	[57]
2016	laparoscopic or robotic surgery	electrosurgery	HBV	[64]
2018	cervix uteri	LEEP	high-risk HPV	[58]

Abbreviations

BPV: bovine papillomavirus; CIN: cervical intraepithelial neoplasia; HEGA: high efficiency gas adsorption; HEPA: high efficiency particulate air; HPV: human papillomavirus; IARC: International Agency for Research on Cancer; LEEP: loop electrosurgical excisional procedure; NIOSH: National Institute of Occupational Safety and Health; OSHA: Occupational and Safety Health Administration; ppm: parts per million.

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Competing Interests

The authors have declared that no competing interest exists.

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