The Nature and Hazards of Diathermy Plumes: A Review

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ABSTRACT

Perioperative nurses in the OR may experience more extensive and sustained exposure to surgical plumes than other surgical personnel. Compared with laser plumes, less policy attention has been given to mitigating the risks associated with exposure to diathermy plumes. Diathermy can produce ultrafine particles and volatile chemical and biological substances, of which a number are teratogenic or carcinogenic. Evidence suggests diathermy plumes contain more biohazards than laser plumes, although protective smoke evacuation equipment is less likely to be used with diathermy. Although there is no direct evidence of harm to OR personnel, further research is required to conclusively establish actual risks and appropriate standards for safe exposure. Interventional strategies should address staff attitudes toward diathermy plume exposure and protective measures. This structured review of the literature describes the nature and risks associated with exposure to diathermy plumes and clarifies the implications for protective techniques and nursing practices. *AORN J* 101 (April 2015) 428-442. ³ AORN, Inc, 2015. <http://dx.doi.org/10.1016/j.aorn.2015.01.021>

Key words: *diathermy plumes, electrosurgery, laser plume, OR safety.*

The use of high-frequency electrical current during electrosurgery to cut or coagulate tissue results in heat and the vaporization and dispersion of fine particles and cellular fluid into the air, creating a plume. More than three decades ago, researchers first identified that surgical plumes, the by-product generated during electrosurgical tissue dissection (ie, diathermy), may contain chemical components and biological particles.^{1,2} Research has confirmed that when plume from different tissue dissection techniques is compared, there are similarities and some notable differences.²⁻⁴ Smaller particles have been shown to arise from diathermy, whereas larger particles result from ultrasonic tissue ablation,⁴ and carbon dioxide (CO₂) laser ablation has been shown to send particles up to 1 m above the surgical site.⁵ Diathermy is capable of liberating an increased number of intact cells compared with the number liberated during laser surgery.⁶

The airborne vapors and particles generated from diathermy may cause harm when inhaled.^{2,7} Awareness of the risks associated with plumes from laser procedures has been heightened because of reports of possible cases of transmission of human papillomavirus (HPV) from patient to surgeon.^{2,6} Consequently, increasing attention has been directed toward understanding and managing the plume generated by laser.^{8,9} Although diathermy remains the most common tissue ablation technique in surgical procedures^{10,11} and there is evidence that the technique is more likely to liberate viable biological material in the plume, it has been reported that use of protective equipment during diathermy is less likely compared with during laser ablation.¹¹

Professional organizations (eg, AORN and the Australian College of Operating Room Nurses [ACORN]) and standards authorities have developed frameworks to guide the management of surgical plumes.^{9,12,13} However, evidence collected in the United States and the United Kingdom suggests precautionary practices are variable, with personnel in the surgical setting reporting inadequate deployment of protective measures.¹¹ In a large study of nurses in Canada and the United States,¹⁴ OR nurses reported that the frequency and use of smoke evacuation equipment was linked to the surgeon's perception of hazard and that a lower level of protection was used with electrocautery compared with laser procedures. Surgeons were reported to minimize the need for evacuation procedures, citing the bulkiness of equipment and decreased visibility of the surgical field as their reasons.^{14,15}

The apparent tolerance to the plume associated with diathermy may reflect the attitudes of staff members who, exposed to this

form of plume without any apparent evidence of harm, simply consider it a routine feature of their work.¹⁶ The continued exposure to potentially harmful smoke, vapors, and particulate matter from diathermy plumes for OR personnel stands in stark contrast to health care facilities that are "smoke free" environments to ensure the protection of workers.¹⁷ As far back as 1981, researchers observed the mutagenic potency of diathermy smoke condensates to be comparable to that of cigarette smoke.¹⁸

LITERATURE REVIEW

Because of the nature of their work, OR nurses are at high risk for exposure to extensive and sustained surgical plume exposures.^{10,17} Given the potential risks associated with diathermy and the apparent ambivalence among medical and nursing personnel to limiting exposure, we addressed the following aims during this review:

- Summarize the available evidence regarding the nature of surgical plumes generated from diathermy.
- Outline what is known about the risks associated with exposure to surgical plumes generated from diathermy.
- Summarize the current evidence regarding protective techniques and standards.
- Identify implications for nursing practice.

Design

To provide a detailed synopsis of the evidence, we included papers published between January 1990 and July 2011 in the review. We chose this time frame after performing an initial review that identified the emergence of literature on this topic from the early 1990s. To provide more in-depth understanding, we sought to identify qualitative, quantitative, and mixed methods studies.

Search Strategy

We accessed the MEDLINE® and CINAHL® electronic databases to perform the search. To identify relevant manuscript titles, abstracts, and subject descriptors, we searched using the terms *surgical plume*, *diathermy plume*, *diathermy smoke*, and *surgical hazards*. We examined the reference lists of the relevant articles found during the initial search to identify other articles not found by the search engines.

Inclusion and exclusion criteria

Initially, a member of our research team screened the abstracts for the identified manuscripts to ascertain if the studies met the following inclusion criteria:

- peer-reviewed research,
- manuscripts published in English,
- substantive reviews, and
- contained specific information about diathermy plume.

This initial screening process, for which the first author screened the full manuscripts to exclude opinion pieces, studies of other modalities, and studies not relevant to the focus of the review from the final analysis, yielded 43 manuscripts. The outcomes of the search and screening process are detailed in Figure 1.

Search outcome

The search strategy yielded 26 appropriate publications. The details of the final manuscripts that we retained in the review are presented in Table 1.

Quality review

Overall, evidence on the nature of the substances present in plumes has been established through small-sample laboratory and clinical studies on human and animal tissue. We rated each of the included studies using guidelines from the Centre for

Evidence-Based Medicine (level 1, highest level; level 5, lowest level). After assessment, most of the studies included in the review (ie, literature reviews, nonrandomized descriptive studies) received a rating of either level 3 (69%) or level 4 (19%).

Tabulation of the Data

We aggregated content analysis¹⁹ detail from the studies into categories based on common concepts.^{20,21} Initially, all members of our research team read each manuscript several times, and then one research team member extracted findings relevant to the aims of the review for compilation into tabular format. All members of our research team verified the accuracy of the extracted findings. As the analysis progressed, one research team member condensed the extracted findings into categories based on common characteristics.

RESULTS

Through the data aggregation process described in the preceding text, we established four categories: (1) composition and properties of plumes produced by diathermy, (2) potential effects of exposure, (3) protective control and standards, and

Figure 1. Summary of search process.

Table 1. Studies Included in This Review Examining Surgical Plumes

Author (date)	Level of Evidence ¹	Research Design	Details	Results
Gatti et al ² (1992)	3	Quasi-experimental e in vitro human (n ¼ 2)	Plume samples were collected after reduction mammoplasty. <i>Salmonella</i> was exposed to the plume to test mutagenicity.	• Changes in the genetic makeup of the <i>Salmonella</i> postexposure suggested mutagenic potential of surgical smoke.
Wenig et al ³ (1993)	3	Quasi experimental e animal	Rats were exposed to cautery plumes and laser plumes over increasing time increments.	• Rats exhibited signs of alveolar congestion and emphysematous changes.
Sood et al ⁴ (1994)	3	Prospective study e human (n ¼ 49)	Surgical plumes were collected in patients undergoing loop electrosurgical excision procedure for <i>cervical intraepithelial neoplasia</i> .	• 37% of samples tested positive for HPV.
Sagar et al ⁵ (1996)	3	Quasi-experimental (n ¼ 6)	Plumes were captured at the point of origin during 6 bowel resections.	• Irritants and carcinogens, including benzene, were detected.
Champault et al ⁶ (1997)	3	Quasi-experimental e human (n ¼ 9)	Surgical plumes were collected during laparoscopic surgery for the removal of benign and metastatic tumors.	• Viable mesothelial cells were collected in 6 of the 9 samples. No tumor cells were identified.
Hensman et al ⁷ (1998)	3	Quasi-experimental e in vitro human	Porcine liver was cauterized and the plumes were collected. Human breast cell carcinoma was exposed to plumes.	• The clonogenicity of the exposed breast cells decreased 30%, emphasizing the cytotoxicity of surgical smoke.
Fletcher et al ⁸ (1999)	3	Quasi-experimental e animal	Surgical plumes were collected during the cautery of mouse melanoma cells.	• Melanoma cells were present in surgical smoke. • Cultured cells were viable for 7 days.
Barrett and Garber ⁹ (2003)	4	Literature review	No detail provided on review methodology; included opinion pieces in review.	• Detail on the nature of diathermy plume was summarized.
Pillinger et al ¹⁰ (2003)	2a	Randomized controlled trial (n ¼ 30)	Investigated the amount of generated diathermy plumes that reached the surgeon's mask during a variety of surgical procedures.	• Suction clearance of the diathermy plumes reduced the amount of smoke reaching the level of the operator's mask.
Scott et al ^{11,12} (2004a), (2004b)	4	Two-part literature review	Summarized the hazards of diathermy plumes.	• Risk assessment of possible occupational exposure was developed.
Hollmann et al ¹³ (2004)	3	Quasi-experimental e human	Captured surgical plumes 2 cm from the origin during a reduction mammoplasty.	• 11 gas components were collected, which detected furfural levels 12 times higher than the recommended exposure limit.

(continued)

Table 1. (continued)

Author (date)	Level of Evidence ¹	Research Design	Details	Results
Krones et al ¹⁴ (2007)	3	Quasi-experimental e animal	Cautery on commercial meat (ie, pork, pork liver) and subcutaneous fat and skin. Cautery was performed over 20 minutes of exposure to surgical plumes. Gas chromatography and mass spectrometry of plume samples.	<ul style="list-style-type: none"> • Cautery produced the most toxic chemicals. • The danger to staff members could not be estimated.
Moot et al ¹⁵ (2007)	3	Quasi experimental e human (n ¼ 6)	Surgical plume from laparoscopy and abdominal surgery. Plumes were analyzed by mass spectrometry.	<ul style="list-style-type: none"> • Several compounds were identified, including hydrogen cyanide, acetylene, and butadiene. • All chemicals were below permissible exposure levels.
Spearman et al ¹⁶ (2007)	3	Cross-sectional survey (n ¼ 169)	An examination of staff attitudes.	<ul style="list-style-type: none"> • Lower level of protection was used with diathermy than with laser.
Al Sahaf et al ¹⁷ (2007)	3	Quasi experimental e human (n ¼ 16)	Samples of surgical plumes were collected during surgery of 20-minute duration.	<ul style="list-style-type: none"> • Different tissues elicited different compounds; several respiratory irritants were identified at levels lower than OSHA standards.
Gates et al ¹⁸ (2007)		Cross-sectional nursing survey; 10-year, 3-stage longitudinal follow-up (n ¼ 86,747)	Primary outcomes of interest for lung cancer diagnosed during time of study.	<ul style="list-style-type: none"> • A history of OR nursing was not associated with lung cancer.
Edwards and Reiman ¹⁹ (2008)	3	Cross-sectional survey (n ¼ 623)	Examination of staff member attitudes to surgical plume control practices.	<ul style="list-style-type: none"> • An inconsistent adoption of plume evacuation procedures was reported. • Evacuation procedures were used less commonly with electrocautery compared with laser procedures.
Bruske-Hohfeld et al ²⁰ (2008)	3	Quasi-experimental e human (n ¼ 6)	Capture of surgical plumes during different abdominal procedures to measure particle concentrations.	<ul style="list-style-type: none"> • Cautery produced ultrafine particles, for which concentrations were highest at the production site and during laparoscopic and intraperitoneal surgery.
Ulmer ²¹ (2008)	4	Literature review	Hazards of surgical smoke.	<ul style="list-style-type: none"> • Summarized the evidence, some of which relates to electrocautery.
Taylor ²² (2009)	4	Literature review	Hazards of surgical smoke.	<ul style="list-style-type: none"> • Compared the dangers of diathermy exposure with the dangers of cigarette smoke.

Table 1. (continued)

Author (date)	Level of Evidence ¹	Research Design	Details	Results
Andréasson et al ²³ (2009)	4	Control group study	Analysis of UFP generated during peritonectomy and compared with standard colon and rectal cancer surgery.	<ul style="list-style-type: none"> UFP were generated in higher concentrations during high-voltage peritonectomy; even in the presence of a high-efficiency particulate absorption filter, the volume of UFP collected during high-voltage peritonectomy was higher than that collected during standard colon surgery.
Ball ²⁴ (2010)	3	Cross-sectional survey (n ¼ 777)	Compliance with smoke evacuation procedures among perioperative nurses during electrosurgical procedures.	<ul style="list-style-type: none"> Knowledge, the complexity of recommendations, and leadership all influenced compliance with evacuation standards.
Chung et al ²⁵ (2010)	3	Prospective study e human (n ¼ 12)	Determine chemical composition of plume generated during transurethral resection of the prostate gland.	<ul style="list-style-type: none"> 16 identifiable compounds were reported, 3 of which were toxic and known carcinogens (1,3-butadiene, vinyl acetylene, acrylonitrile). The gas filter was reported to trap 97% of chemical components in plumes.
Lin et al ²⁶ (2010)	3	Prospective study e human (n ¼ 30)	Analysis of electrocautery plumes collected during mammoplasties.	<ul style="list-style-type: none"> Higher-than-recommended levels of toluene were found in all samples.
Wu et al ²⁷ (2011)	3	Quasi-experimental e human (n ¼ 30)	Surgical plumes collected during mastectomy and abdominal surgery.	<ul style="list-style-type: none"> Toluene was collected in 90% of the plume samples.
Fitzgerald et al ²⁸ (2012)	2	Single-blind controlled study (n ¼ 10)	The capture of surgical plumes in laparoscopic surgery.	<ul style="list-style-type: none"> 6 carcinogenic or irritant hydrocarbons (ie, benzene, ethylbenzene, styrene, toluene, heptene, methylpropene) were identified in one or more samples.

OSHA ¼ Occupational Safety and Health and Administration; UFP ¼ ultrafine particles

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(4) practices and attitudes of OR personnel. Each of the resultant categories is described in the following text.

Composition and Properties of Plumes Produced by Diathermy

Detailed investigation of the compounds in plumes occurred largely after 1992 because earlier studies were unable to identify the organic compounds, owing to limitations of the available analytic techniques. Initial investigations focused on identifying whole cells and the mutagenic and cytotoxic actions of plumes on biological cultures.^{20,21} Later studies identified and quantified the nature of the organic chemical compounds present.²²⁻²⁴ The chemical substances found in diathermy plumes are summarized in [Table 2](#).

Chemical composition

Of the studies reviewed, most published since 2000 sought to comprehensively identify and quantify the chemical cocktail contained in diathermy plumes. The content of surgical plumes varies according to the following:

- type of tissue dissected, and
- nature of the surgery performed.

Muscular tissue cut by diathermy produces higher levels of aldehydes and ketones, while the coagulation of liver and fatty

tissue liberates carbon monoxide and hydrocyanic acid.³ Studies have shown that epidermal tissue ablation produces higher levels of xylene, toluene, and ethyl benzene.^{25,26} Studies have also confirmed that the higher the temperature, the more toxic the chemical components found in the plume.³ In a study that consisted of 30 diathermy smoke samples collected during mastectomy and abdominal cavity operations, the researchers detected toluene in 90% of the samples, with concentrations of 0.003 mg/m³ to 0.463 mg/m³ (which is below the National Institute for Occupational Safety and Health safe exposure level ceiling of 0.14 mg/m³). Of these samples, the researchers identified very few cases of ethyl benzene and styrene.²⁷ Linear regression analysis identified that surgery type, patient age, and electrocautery duration explained approximately 68% of the variation in toluene production.

In another study, all samples collected during diathermy in breast surgery had identified levels of toluene between 2.48 mg/m³ and 5.50 mg/m³, with higher concentrations observed during radical mastectomies.²⁸ In the study by Wu et al, toluene produced during a single episode of breast surgery exceeded 1 mg. The permissible exposure limit for acute exposure to toluene (less than 14 days) to which most workers can be exposed without adverse effects has been suggested to be 75 mg/m³ averaged over a 40-hour workweek and not to exceed 0.135 mg/m³ for a 10-hour work shift.²⁷ For chronic exposure

Table 2. Chemical Substances Identified in Diathermy Plume¹⁻³

Chemical Substance	Exposure Considerations
Aldehydes: acetaldehyde, formaldehyde, acrylamide	<ul style="list-style-type: none"> The vapor is a respiratory tract irritant Considered by NIOSH to be a potential occupational carcinogen Use and exposure are increasingly regulated; maximum exposure limit is 0.05 ppm
Ketones	<ul style="list-style-type: none"> Exposure can cause local irritation and peripheral neuropathy Standards exist for safe exposure; the 8-hour exposure limit is 590 mg/m³
Benzene	<ul style="list-style-type: none"> Considered by NIOSH to be a potential occupational carcinogen Exposure should be reduced to lowest possible limit <ul style="list-style-type: none"> Short-term exposure limit is 5 ppm in any 15-minute period
Xylene	<ul style="list-style-type: none"> Volatile organic compound Respiratory irritant, skin irritant; eye damage can occur from exposure to higher concentrations 8-hour exposure limit is 435 mg/m³
Toluene	<ul style="list-style-type: none"> Exposure can cause headaches, nausea, and dizziness NIOSH recommends biennial medical examinations for exposed workers Short-term exposure limit should not exceed 0.14 mg/m³; for a 10-hour work shift, the limit is 0.135 mg/m³
Styrene	<ul style="list-style-type: none"> Inhalation and skin exposure can result in occupational injury Adverse effects on CNS have been observed Considered by NIOSH to be a teratogen and carcinogen
Furfural	<ul style="list-style-type: none"> Eye and respiratory tract irritant Limited data to establish safe exposure limits
Methylpropene, ethylene, propanenitrile	<ul style="list-style-type: none"> No identified safe exposure limits
Hydrogen cyanide/hydrocyanic acid	<ul style="list-style-type: none"> Exposure affects CNS and cardiovascular system NIOSH specifies exposure limits for air respirators only
1,3-Butadiene	<ul style="list-style-type: none"> Considered by NIOSH to be a teratogen and carcinogen
NIOSH ¹ /4 National Institute for Occupational Safety and Health; CNS ¹ /4 central nervous system 1. National Institute for Occupational Safety and Health (NIOSH): Current Intelligence Bulletin 55. Carcinogenicity of acetaldehyde and malonaldehyde, and mutagenicity of related low-molecular-weight aldehydes. September 1991. Centers for Disease Control and Prevention. http://www.cdc.gov/niosh/docs/91-112/ . Accessed January 15, 2015. 2. NIOSH Pocket Handbook Guide to Chemical Hazards. 2nd ed. Neenah, WI: J. J. Keller Associates; 2005. 3. Control of smoke from laser/electric surgical procedures [NIOSH publication number 96-128]. 1996. Centers for Disease Control and Prevention http://www.cdc.gov/niosh/docs/hazardcontrol/hc11.html . Accessed January 15, 2015.	

(defined as 364 days or more of exposure), inhalation exposure is recommended to be 0.3 mg/m³.²⁹ In comparison, the public is generally exposed to approximately 0.3 mg of toluene daily in environmental air, and those who smoke a pack of cigarettes per day are exposed to 1 mg.²⁹ Given that background levels of toluene may meet minimum exposure levels, additional workplace exposure may exceed safe minimum levels. Findings from these studies suggest that chronic exposure levels for OR personnel regularly exposed to diathermy plumes during breast surgery may exceed minimal risk levels.

To compare the plumes generated by diathermy, argon beam, and ultrasonic dissection methods, Krones et al³ undertook a laboratory

study on porcine tissue. They reported that benzene, acrylamide, formaldehyde, carbon monoxide, hydrogen cyanide, and acetaldehyde were present in the plume. In this study, higher temperatures yielded aerosols that were more toxic. The composition and toxicity of plumes varied according to the type of tissue processed, energy level used, and surgical technique. All dissection methods produced aerosols with detectable toxic components. Of note, diathermy produced the greatest concentration of toxic aerosols, with higher temperatures resulting in more toxic components. Formaldehyde and toluene, however, are present in the ambient air of ORs.²⁴ Because the background levels of these chemicals were not concurrently investigated, it is not possible to determine whether the

formaldehyde present in the surgical plumes in this study arose from the OR environment.

In another small study of reduction mammoplasty, researchers identified 11 gaseous chemicals as having been released in the surgical plume 2 cm from the cautery device. All of these chemicals were below permissible exposure levels with the exception of toluene and furfural, which were reported to be 12 times greater than the allowable occupational exposure limit.²⁴ Furfural is used as a solvent in the petrochemical industry. In its gaseous form, it acts as a strong respiratory irritant.²⁴ A number of other substances detected in the study, such as methylpropene, ethylene, and propanenitrile, have no identified safe exposure limits.²⁴

Two other studies of plume generated during human abdominal and transurethral surgery reported the potent respiratory irritant cyclohexane and carcinogens (ie, 1,3-butadiene, vinyl acetylene, acrylonitrile) as major components of the plumes.^{30,31} Other authors reported volatile organic compounds identified in diathermy plumes to include the cardiotoxic compound hydrogen cyanide and the carcinogenic compound 1,3-butadiene.⁴

Biological properties

The plumes generated during diathermy contain a variety of biological substances that are remnant materials from body tissues and fluids. Establishing the viability of the biological substances liberated in plumes is relevant to identifying any risk of disease transmission.

Interest in the ability of diathermy to liberate viable biological substances within plume led Fletcher, Mew, and DesCoteaux to conduct a laboratory-based study that examined two issues³²: (1) whether live malignant cells were present in the plumes and (2) quantifying the number of cells and the influence of the diathermy current level on the viability of vaporized cellular material. In the first part of this study, the researchers cauterized mouse melanoma cells using average power levels applied for five minutes, after which they collected and then cultured the plumes. Although Fletcher, Mew, and DesCoteaux identified viable intact melanoma cells immediately after plume collection, analysis of these cells showed them to be nonviable. In contrast, in the second part of this study, this research team investigated three power settings and shorter durations of cautery in an effort to more closely emulate typical surgical practice. The lower cautery levels yielded higher cell counts with viable cells that were successfully cultured from the plumes at seven days. These findings suggest that typical diathermy procedures that use

lower current over shorter periods may generate plumes that contain viable malignant cells.³²

Other studies have focused on the mutagenicity and cytotoxicity of diathermy plume. In 1992, Gatti et al²² undertook a study to determine the mutagenicity of the plumes produced during two reduction mammoplasty procedures. These researchers used a laboratory culture model, and their findings demonstrated that the plumes collected during the surgeries were mutagenic to a strain of *Salmonella*. In a subsequent laboratory study with liver tissue from porcine, other researchers demonstrated that diathermy plumes were cytotoxic to a cultured human cell line.²³

In a small human patient study (n ¼ 9) that tested whether cells could be liberated in the plumes created during laparoscopic surgery, Champault et al³³ reported that whole mesothelial cells were identified in six of the nine plume samples collected. The original focus of this study was to identify a mechanism for the formation of port site metastases after laparoscopic surgery. The researchers postulated the metastasis occurred through the liberation of viable cells during surgery, resulting in subsequent tumor growth at port sites. The samples containing cells were from laparoscopic surgery conducted over a number of hours. Although the viability of the cells was not studied, the cells appeared whole and took up cytochemical stains. In addition to finding intact mesothelial cells in the same study, electron micrographs showed many other cells that on visual examination appeared to be blood cells. These cells, however, were not analyzed further. The results of this study have potential implications for OR staff members who are subjected to pressurized plumes vented in their vicinity when the laparoscopic ports are opened.^{33,34} Another small-sample study (n ¼ 10) of surgical plumes generated during laparoscopic surgery identified that both electrocautery and ultrasonic dissection were associated with significantly lower concentrations of the most commonly detected carcinogenic and irritant hydrocarbons when compared with cigarette smoke.¹⁵

Investigations into the nature of viral substances in diathermy plumes are sparse. Sood et al⁶ conducted a study of samples collected during loop electrosurgical excision procedures for abnormal cervical cell changes (n ¼ 49). In the study, 39 of the 49 patient plume samples were reported to be positive for HPV. Although Barrett and Garber² suggest that the infectivity of viral particles in diathermy plumes has been confirmed, no evidence to support this argument was provided in the literature review in that study. In addition, no studies were identified that examined the potential transmissibility of viral particles in diathermy plumes. It appears that most available studies have examined viral particles generated in laser plumes, with a suggestion of

transmission of HPV between a patient and a surgeon.² In the absence of additional studies, it is not possible to confirm whether the lower temperature settings used in diathermy leads to a greater viable viral load compared with other dissection modalities.

Potential Effects of Exposure to Diathermy Plumes

A number of researchers have sought to identify the nature and extent of any risks associated with exposure to plumes. Possible adverse effects of exposure to diathermy plumes relate to the chemical content, the size of the particles, and the pathogenic viability of biological substances contained in the plumes. Given what is known about the particle size and chemical content of plumes, associations have been drawn by researchers between the inhalation of diathermy particulate matter and the harmful effects of passive exposure to cigarette smoke air pollutants.^{2,4,17}

When comparing the content of diathermy plumes with cigarette smoke, investigators have alluded to possible similar adverse consequences of exposure.¹⁷ Although Ulmer⁷ determined that particles, biological substances, and chemical substances capable of causing harm are present in diathermy plumes, this study did not provide substantive evidence regarding the potential dangers of exposure. When conducting this review, we identified only one study (Wenig et al³⁵) that examined the effects of exposure to plumes. In this small laboratory study, the researchers exposed rats to diathermy plumes; on postmortem examination, the exposed rats were noted to show histological lung changes.³⁵

Few studies have examined exposure rates or patterns for perioperative personnel. Consequently, little if anything is known about the possible consequences of exposure. To explore the relationship between exposure to respiratory irritants and carcinogens in surgical plume, one study enrolled nurses for a decade and monitored the reported rates of lung cancer diagnosed during this period.³⁶ The analysis reported that a history of nursing in the OR setting was not associated with an increased rate of lung cancer among the study subjects. In another cross-sectional survey study (n ¼ 777), perioperative nurse respondents were reported to experience a higher rate of respiratory symptoms compared with the general population. In this study, 22.9% of the perioperative nurses surveyed reported sinus infections/problems, compared with 10.3% of the general population. Nurses in this study also reported higher rates of allergies (24.2% vs 18.4%), asthma (10.9% vs 6.4%), and bronchitis (9% vs 4.5%).³⁴

Protective Control and Standards

The potentially harmful chemical and biological substances identified in diathermy plumes raise questions regarding the protection of OR personnel from exposure. A number of studies have sought to establish whether masks provide adequate respiratory protection against the inhalation of surgical plumes.

Control measures and particle size

Surgical masks have been in use since the early 1990s and were originally designed to minimize surgical wound infections from bacteria spread by OR staff members. Most surgical masks only filter particles to approximately 0.5 mm in size; however, the majority of particles in plumes are ultrafine and much smaller.³⁷

A small number of studies have examined the particle size of substances generated from diathermy. Compared with laser and ultrasonic tissue ablation, diathermy generates plume with the smallest particle sizes, as reported by researchers in one study.² A 2008 study by Bruske-Hohlfeld et al⁴ examined ultrafine particles collected during six different types of surgical procedures. The particles ranged in size from 10 nm to 1 μm.⁴ These authors reported a short period of very high exposure to ultrafine particles (> 100,000/m³) for surgeons and close-assisting surgical personnel. Another study that collected ultrafine particles (0.02 μm to 1 μm) from the breathing area of surgeons during high-voltage cautery peritonectomy reported that the use of a high-efficiency particulate absorption (HEPA) filter during the procedure did not limit exposure to ultrafine particles.³⁸ To date, the nature of these ultrafine particles in diathermy plumes remains largely unexplored. If inhaled, these ultrafine particles are small enough to accumulate in alveolar tissue or be taken up into cells.⁴

A 2008 study evaluated filter performance and facial fit of standard surgical masks.³⁷ The results were concerning. None of the masks tested exhibited adequate filter performance or the facial-fit characteristics necessary for respiratory protection. One of the masks tested demonstrated high filter efficiency but the lowest fit factor. The researchers highlighted the importance of fit in preventing inward leakage of particles, with up to 10% to 40% of particles penetrating the face seal as a result of poor fit.³⁷

At the time of activating diathermy, a cloud of ultrafine particles may be observed, after which the volume of particles falls into a lower background level.⁴ Establishing the size of the particles liberated is important because traditional surgical masks are known to provide ineffective protection against

inhaling fine or ultrafine particles.³⁷ If inhaled, particles smaller than 2.5 μm precipitate in the alveolar region of the lung and may enter the bloodstream and reach other organs. Particles of this size can also include viruses and bacteria,³⁹ Particle size fractions below 100 nm may be taken up into cells⁴ and may interact with biomolecular or cellular activities or accumulate if nondegradable.

Evacuation techniques

Two studies in this review examined evacuation techniques and found that use of evacuation systems leads to a reduction in volume or concentration of plumes. Pillinger et al¹⁰ conducted a randomized controlled clinical trial (n = 30) to investigate the amount of diathermy plume that reached the surgeon's mask during a variety of surgical procedures. In this study, the extraction system was placed at the level of the surgery and the particles were measured at the level of the operator's mask. For the evacuation group, there was a marked reduction in the volume of plume reaching the surgeon's mask. Additionally, in the presence of a very efficient ventilation system, the increment and decrement of ultrafine particles occurs within a matter of seconds.⁴

Protective standards

There are several standards that specify acceptable exposure limits to atmospheric contaminants in the work environment.^{40,41} Of note, these standards relate to inert particles. In contrast, much of the particulate matter in diathermy plumes is biological substances that currently have no known safe exposure levels. In the absence of standards on acceptable exposure limits, it is not possible to determine risks of exposure or whether control measures are adequate. In the absence of substantive evidence to confirm or refute any link to adverse effects from exposure to diathermy plumes, caution is advisable. AORN has established perioperative guidelines to ensure a healthy work environment.¹³ Similarly, in Australia, ACORN has published a standard that addresses the management of surgical plumes, whether generated through diathermy or laser.¹² These standards recommend that appropriate equipment and procedures be used to prevent exposure to plumes and that exposure is minimized with capture devices. Standards Australia has produced a guide (ie, AS/NZS 4173:2004⁹) for the safe use of lasers in health care. This standard recommends that airborne contaminants be captured as close to the point of origin as possible and be removed by a localized exhaust ventilation system (ie, smoke evacuator), with all materials used to collect these airborne contaminants considered a biohazard and disposed of accordingly. Masks are not recommended as the first line of protection.⁹

Practices and Attitudes of OR Personnel

The attitudes of OR personnel toward diathermy plumes were the focus of three of the studies identified in this review. In the 2007 UK study, Spearman et al¹¹ sent 169 questionnaires to general surgical consultants (ie, senior medical specialists) (n = 103), specialist registrars (ie, medical officers undertaking postgraduate specialist training) (n = 52), and senior OR nurses (n = 14). The researchers sought to elicit information regarding the degree of diathermy use among surgeons, the attitudes of the nursing and surgical staff members toward plumes, perceptions regarding the hazards of inhalation, and the measures in place to reduce plume exposures. The investigators also asked those surveyed whether they had any knowledge of adverse events associated with surgical plumes and whether they felt current practices in their workplace were adequate.¹¹ Registrars were more likely to use evacuation equipment (70%) compared with consultants (43%), with standard wall-mounted suction the most commonly used equipment to clear the surgical field of plumes. Most of those surveyed perceived plumes to be potentially harmful and protective precautions to be inadequate. The researchers reported there was some uncertainty among the consultant group as to the dangers of diathermy plumes, with many believing more evidence was required. Nurses reported not feeling empowered regarding the use of protective equipment, the use of which was at the discretion of surgeons. The researchers suggested the need for greater awareness of both the hazards of plumes and plume evacuation technology.

A large study¹⁴ of nurses in Canada and the United States (n = 623) investigated the types of control measures and respiratory protection in use. The web-based survey recruited members of AORN and included representation from all 50 US states and Canada. Of the respondents, 86% were perioperative RNs. The researchers linked the frequency of evacuation use to a clinician's perception of hazard or the volume of surgical smoke produced. Nurses in the study reported using a lower level of protection with diathermy compared with laser procedures, and the most frequently reported reason for noncompliance with smoke evacuation was the surgeon's resistance or refusal.

DISCUSSION

This review focuses on diathermy plumes. Differentiating between laser and diathermy plumes proved problematic because a number of studies classified the two modalities together. As a result, data collected in studies of laser plumes are commonly used to substantiate claims about diathermy. A distinction needs to be made between the two sources of

KEY TAKEAWAYS FOR CLINICAL PRACTICE

The Nature and Hazards of Diathermy Plumes: A Review

WHY DID WE DO THIS RESEARCH?

- We undertook this structured review of the literature to summarize evidence about the nature and risks associated with exposure to diathermy plumes to inform nursing practice.

WHAT DID WE FIND?

- Diathermy plumes contain chemical and biological substances that are considered mutagenic, carcinogenic, and possibly infectious, including whole cells and viral particles.
- Evidence suggests that diathermy plumes may contain more biohazards than do laser plumes.
- Protective smoke-evacuation equipment is less likely to be used with diathermy.
- Staff member attitudes of tolerance toward diathermy plume exposure should be addressed.
- Current evidence warrants protective measures and work process redesign (eg, related to plume evacuation technology) to limit exposure to diathermy plumes.

HOW CAN CLINICIANS USE THESE RESULTS?

- Clinician: Perioperative team members should use protective measures when potentially exposed to diathermy plumes.
- Manager: Managers should ensure that protective guidelines and written policies exist for the appropriate use of protective equipment during diathermy ablation. Consideration should be given to work process redesign to minimize OR staff exposure to surgery types that produce high volumes of hazardous diathermy plumes.
- Educator: Educators should conduct training and inservice programs to educate perioperative team members about the hazards of diathermy plumes and how to protect themselves from exposure to airborne contaminants.

Lindsey C, Hutchinson M, Mellor G. The nature and hazards of diathermy plumes: a review. AORN J. 2015;101(4):428-442.

plumes because there is sufficient evidence to suggest the plume differs in both quality and quantity between these two modalities.

Most studies investigating diathermy plumes are small-sample studies commonly using laboratory-based animal samples. The ethical issues associated with studying human exposure, particularly the investigation of metastatic tissue plume, are a contributing factor to the prevalent use of animal studies.^{23,32} Although early studies examined biological material contained in plumes, more recent studies have focused on the chemical

composition of plumes. This shift may reflect the difficulties associated with measuring exposure to human tissue plumes and substantiating the nature of ultrafine particles.

Although diathermy remains the most common form of surgical tissue ablation technique, it appears that greater attention has been directed toward investigating the characteristics of the plumes of laser procedures. As a consequence, it is known that laser plume transmits viral particles. For example, it has been recognized for more than 20 years that HIV proviral DNA is present in laser smoke.⁴² Human papillomavirus DNA can

also be released during laser vaporization of genital HPV infections.⁴³ In contrast, there has been limited examination of the biological risks associated with diathermy. Although many researchers continue to detail the similarities and some even allude to there being no difference between the various forms of plumes, this review did not find a study stating conclusively that plume components generated by laser and diathermy are the same.

Evidence suggests that OR personnel can exhibit tolerant attitudes toward exposure to diathermy plumes that are not present during laser procedures, in which preventive measures are more likely to be used. Decades of exposure to surgical plumes, with few apparent negative consequences, may have reinforced these attitudes. Reflecting the growing body of evidence on the potential hazards of both electrosurgical and laser diathermy, professional organizations, such as AORN, advocate for the use of smoke evacuators or in-line filters for both electrosurgical and laser diathermy.¹³ Strong leadership in the implementation of such guidelines and continued education may mitigate the tolerance to exposure to diathermy plumes.

Recommendations for Future Research

Fine particulate air pollution is associated with increased morbidity and mortality.² Surgical staff members, particularly nurses, experience continual long-term exposure to airborne particulate matter. This exposure poses a health risk. In light of evidence that exposure to surgical plumes is potentially hazardous, it is interesting that there has been little investigation of the effects on exposed personnel. The need for more research is a continuing theme through the medical literature on diathermy plumes. The absence of empirical data on actual exposure levels for OR staff members is a notable factor that limits the development of informed management strategies. There is also a need for additional studies that explore the attitudes of staff members and why precautionary measures are not used.

Most researchers agree that until more definitive data are available, particularly on exposure rates and limits, it is best to err on the side of caution.⁴ It is likely that the most important safety measure to protect staff members against the potential risks associated with exposure to surgical plume is a reliable ventilation system that effectively filters out gases and all freshly produced particles. To mitigate the potential undesirable effects of exposure to plumes, the most frequent recommendation that we identified during this review is that OR personnel use conservative standards, such as smoke evacuation, regardless of

the duration of exposure. The cost implication of smoke evacuation during all surgical procedures is considerable. As a result, the cost of introducing extraction equipment for all surgical ablation procedures is prohibitive and the compliance associated with this equipment is problematic, so the use of smoke evacuation requires substantive evidence on the nature and extent of the risk.

Implications for Practice

The tolerant attitudes of OR staff members to the possible risks of diathermy plumes appear to be a significant problem. The reasons behind these attitudes should be investigated, because lack of concern may be one of the reasons why evacuation devices or other precautions are not used. Additional empirical data are also required on the optimal efficiency of ventilation systems to inform policy and standards.

Limitations of This Study

One limitation of this analysis is that many of the studies reviewed were small samples or used animal tissue. An additional limitation is that many of the articles reviewed were literature reviews that presented summarized opinion.

CONCLUSION

Studies in the literature portray a partial picture of diathermy plumes as potentially serious occupational hazards in the perioperative setting. Diathermy plumes contain chemical and biological substances that are considered mutagenic, carcinogenic, and possibly infectious, including whole cells and viral particles. A number of areas require more investigation and research, and there is a need for long-term studies on exposure limits. Although the chemical and biological composition of surgical smoke is not yet fully confirmed, current evidence warrants cautionary measures to prevent exposures. The fact that OR personnel are exposed after long periods is cause for concern, particularly in the absence of clear data on exposure risks.

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