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

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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.*
Conclusions *Study findings can be used to raise awareness of the marginal use of exposure controls and impediments for their use.* Am. J. Ind. Med. 59:1020–1031, 2016. Published 2016. This article is a U.S. Government work and is in the public domain in the USA

KEY WORDS: 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

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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

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
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

(*Continued*)

TABLE I. (*Continued*)

Characteristic	Laser surgery (n[a]) percent[b]	Electrosurgery (n[a]) percent[b]
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 exactly 100% due to rounding.

(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%)

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 past 12 months	23	24
Yes, more than 12 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 exactly 100% due to rounding.

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.

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 exactly 100% due to rounding.

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).

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 than 100% 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.

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.

TABLE V. Proportion Reporting LEV Always Used by Workplace and Employee Characteristic

	Laser surgery			Electrosurgery		
% reporting LEV always used	**n**	**Percent**	***P*-value**	**n**	**Percent**	***P*-value**
Received training addressing hazards of surgical smoke						
Yes, within the past 12 months	297	61	<0.01[a]	1,093	21	<0.01[a]
Yes, more than 12 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	
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	

(*Continued*)

TABLE V. (*Continued*)

% reporting LEV always used	Laser surgery n	Laser surgery Percent	Laser surgery *P*-value	Electrosurgery n	Electrosurgery Percent	Electrosurgery *P*-value
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	
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.

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.

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.

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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.

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Steven Markowitz declares that he has no competing or conflicts of interest in the review and publication decision regarding this article.

DISCLAIMER

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REFERENCES

Alp E, Bijl D, Bleichrodt RP, Hansson B, Voss A. 2006. Surgical smoke and infection control. J Hosp Infect 62(1):1–5.

American National Standard Institute (ANSI). 2005. American national standard for safe use of lasers in health care facilities. ANSI Z136.3-2005. Accessed June 27, 2014 at http://webstore.ansi.org/RecordDetail.aspx?sku=ANSI+Z136.3-2011

American Society for Laser Medicine and Surgery (ASLMS). 2007. Smoking guns—Parts 1 and 2. Accessed June 30, 2014 at http://www.aslms.org/public/smokingguns1.shtml; http://www.aslms.org/public/smokingguns2.shtml

Association of periOperative Registered Nurses (AORN) 2014a. Recommended practices for laser safety in perioperative practice settings. In: Standards, recommended practices, and guidelines. Denver, CO: AORN, Inc. pp. 141–154.

Association of periOperative Registered Nurses (AORN) 2014b. Recommended practices for electrosurgery. In: Ramona Connor, editor. Perioperative standards and recommended practices. Denver, CO: AORN, Inc. pp. 123–139.

Association of Surgical Technologists (AST). 2012. AST Standards of Practice for use of electrosurgery. Accessed October 8, 2015 at http://www.ast.org/uploadedFiles/Main_Site/Content/About_Us/Standard%20Electrosurgery.pdf

Baggish MS, Elbakry M. 1987. The effects of laser smoke on the lungs of rats. Am J Obstet Gynecol 156(5):1260–1265.

Ball K. 2010a. Compliance with surgical smoke evacuation guidelines: Implications for practice. AORN J 92(2):42–49.

Ball K. 2010b. Surgical smoke evacuation guidelines: Compliance among perioperative nurses. AORN J 92(2):e1–e23.

Bigony L. 2007. Risks associated with exposure to surgical smoke plume: A review of the literature. AORN J 86(6):1013–1020.

Canadian Centre for Occupational Health and Safety. 2014. Laser plumes—Health care facilities. Accessed March 4, 2016 at http://www.ccohs.ca/oshanswers/phys_agents/laser_plume.html

Centers for Disease Control and Prevention (CDC). 2010. Distinguishing public health research and public health nonresearch. Accessed September 4, 2015 at http://www.cdc.gov/od/science/integrity/docs/cdc-policy-distinguishing-public-health-research-nonresearch.pdf

Edwards BE, Rieman RE. 2008. Results of a survey on current surgical smoke control practices. AORN J 87(4):739–749.

Edwards BE, Rieman RE. 2012. Comparison of current and past surgical smoke control practices. AORN J 95(3):337–350.

Emergency Care Research Institute (ECRI). 2007. Laser use and safety. In: Healthcare risk control. Vol. 1. Plymouth Meeting, PA: ECRI, November 2007.

Garden JM, O'Banion MK, Bakus AD, Olson C. 2002. Viral disease transmitted by laser-generated plume (aerosol). Arch Dermatol 138(10):1303–1307.

Gatti JE, Bryant CJ, Noone RB, Murphy JB. 1992. The mutagenicity of electrocautery smoke. Plast Reconstr Surg 89(5):781–784.

Gorman T, Dropkin J, Kamen J, Nimbalkar S, Zuckerman N, Lowe T, Szeinuk J, Milek D, Piligian G, Freund A. 2013. Controlling health hazards to hospital workers: A reference guide. New Solut 23(Suppl):1–167.

Hallmo P, Naess O. 1991. Laryngeal papillomatosis with human papillomavirus DNA contracted by a laser surgeon. Eur Arch Otorhinolaryngol 248:425–427.

Harkavy LM, Novak DA. 2014. Clearing the air: Surgical smoke and workplace safety practices. OR Nurse 8(6):1–7.

King B, McCullough J. 2001. Hazard evaluation and technical assistance report. HETA No. 2001-0066-3019, Morton Plant Hospital, Dunedin, FL. Accessed June 26, 2014 at http://www.cdc.gov/niosh/hhe/reports/pdfs/2001-0066-3019.pdf

Manuele FA. 2005. Risk assessment and hierarchy of control. Prof Safety 50(May 2005):33–39.

Ministry of Health, New South Wales, Australia. 2015. Government Guideline GL 2015-002. Work health and safety—Controlling exposure to surgical plume. Accessed March 4, 2016 at http://www0.health.nsw.gov.au/policies/gl/2015/pdf/GL2015_002.pdf

National Institute for Occupational Safety and Health (NIOSH). 1996. Control of smoke from laser/electric surgical procedures. NIOSH Pub. No. 96-128. Accessed September 4, 2015 at http://www.cdc.gov/niosh/docs/hazardcontrol/hc11.html

Novak DA, Benson SM. 2010. Understanding and controlling the hazards of surgical smoke. Prev Infect Ambul Care 1:3–5.

Occupational Safety and Health Administration (OSHA). 2015. Laser/electrosurgery plume. Accessed September 4, 2015 at https://www.osha.gov/SLTC/etools/hospital/surgical/surgical.html

Pierce JL, Lacey SE, Lippert JF, Lopez R, Franke JE. 2011. Laser-generated air contaminants for medical laser applications: A state-of-the-science review of exposure characterization, health effects and control. J Occup Environ Hyg 8(7):447–466.

Sawchuk WS, Weber PJ, Lowy DR, Dzubow LM. 1989. Infectious papillomavirus in the vapor of warts treated with carbon dioxide laser or electrocoagulation: Detection and protection. J Am Acad Dermatol 21(1):41–49.

Spearman J, Tsavellas G, Nichols P. 2007. Current attitudes and practices towards diathermy smoke. Ann R Coll Surg Engl 89(2):162–165.

Steege AL, Boiano JM, Sweeney MH. 2014. NIOSH health and safety practices survey of healthcare workers: Training and awareness of employer safety procedures. Am J Ind Med 57(6):640–652.

Tomita Y, Mihashi S, Nagata K, Ueda S, Fujiki M, Hirano M, Hirohata T. 1981. Mutagenicity of smoke condensates induced by CO2-laser irradiation and electrocauterization. Mutat Res 89(2):145–149.

Ulmer BC. 2008. The hazards of surgical smoke. AORN J 87(4):721–738.

Wilks SS. 1959. Effects of pure carbon monoxide gas injection into the peritoneal cavity of dogs. J Appl Physiol 14(3):311–312.

Winston C. 1994. The effects of smoke plume generated during laser and electrosurgical procedures. Minim Invasive Surg Nurs 8(3): 99–102.

SUPPORTING INFORMATION

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

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