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Precautionary practices for administering anesthetic gases: A survey of physician anesthesiologists, nurse anesthetists and anesthesiologist assistants

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ABSTRACT

Scavenging systems and administrative and work practice controls for minimizing occupational exposure to waste anesthetic gases have been recommended for many years. Anesthetic gases and vapors that are released or leak out during medical procedures are considered waste anesthetic gases. To better understand the extent recommended practices are used, the NIOSH Health and Safety Practices Survey of Healthcare Workers was conducted in 2011 among members of professional practice organizations representing anesthesia care providers including physician anesthesiologists, nurse anesthetists, and anesthesiologist assistants. This national survey is the first to examine self-reported use of controls to minimize exposure to waste anesthetic gases among anesthesia care providers. The survey was completed by 1,783 nurse anesthetists, 1,104 physician anesthesiologists, and 100 anesthesiologist assistants who administered inhaled anesthetics in the seven days prior to the survey. Working in hospitals and outpatient surgical centers, respondents most often administered sevoflurane and, to a lesser extent desflurane and isoflurane, in combination with nitrous oxide. Use of scavenging systems was nearly universal, reported by 97% of respondents. However, adherence to other recommended practices was lacking to varying degrees and differed among those administering anesthetics to pediatric (P) or adult (A) patients. Examples of practices which increase exposure risk, expressed as percent of respondents, included: using high (fresh gas) flow anesthesia only (17% P, 6% A), starting anesthetic gas flow before delivery mask or airway mask was applied to patient (35% P; 14% A); not routinely checking anesthesia equipment for leaks (4% P, 5% A), and using a funnel-fill system to fill vaporizers (16%). Respondents also reported that facilities lacked safe handling procedures (19%) and hazard awareness training (18%). Adherence to precautionary work practices was generally highest among nurse anesthetists compared to the other anesthesia care providers. Successful management of waste anesthetic gases should include scavenging systems, hazard awareness training, availability of standard procedures to minimize exposure, regular inspection of anesthesia delivery equipment for leaks, prompt attention to spills and leaks, and medical surveillance.

KEYWORDS
Anesthesia care providers; anesthetic gases; exposure controls; precautionary practices; web survey

Introduction

One of the principle goals of general anesthesia is to prevent patients from feeling pain during surgery. Each year in the U.S., an estimated 20 million patients undergo surgery where inhaled anesthetics are used.[1] Two classes of inhaled anesthetics are used in medical (i.e., non-dental) procedures: halogenated agents (vaporized liquids) and nitrous oxide (gas). Halogenated anesthetics include enflurane, desflurane, halothane, isoflurane, and sevoflurane and are typically administered in combination with nitrous oxide to produce surgical levels of anesthesia. Inhaled anesthetics are administered by anesthesia care providers (i.e., physician anesthesiologists, nurse anesthetists, and anesthesiologist assistants) via face mask, laryngeal mask airway, or tracheal tube connected to an anesthesia machine. Anesthetic gases and vapors that leak into the surrounding room during medical procedures are considered waste anesthetic gases.[2] More than 250,000 healthcare workers in the U.S. may be exposed to waste anesthetic gases and are at risk of developing adverse health effects.[2]

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Acute exposure to halogenated anesthetics has been shown to cause headache, irritability, fatigue, nausea, drowsiness and difficulties with judgement and coordination.[3] Chronic exposure to waste anesthetic gases has been linked to spontaneous abortion, congenital anomalies, genetic damage and cancer.[3–13] Some studies, however, report no adverse health effects from long-term exposure to low concentrations of waste anesthetic gases.[14,15] Because health risks to some of the more common and newer anesthetics (e.g., isoflurane, desflurane, and sevoflurane) have not been fully evaluated, the Occupational Safety and Health Administration (OSHA) recommends that exposures be kept to a minimum.[16]

Acute exposure to nitrous oxide may cause lightheadedness, eye and upper airway irritation, cough and shortness of breath.[17] Chronic exposure to nitrous oxide among female dental assistants and operating room workers may cause reduced fertility, spontaneous abortion, and neurologic, renal, and liver disease, as well as decreases in mental performance and manual dexterity.[18–21]

Methods of minimizing worker exposure to waste anesthetic gases have been addressed by government agencies and professional practice organizations.[16,21–24] These guidelines are generally consistent with respect to primary prevention measures and application of a hierarchical approach for control technologies to mitigate workplace hazards.[25] This approach specifies that unless the hazard can be substituted by a substance less toxic or eliminated (i.e., total intravenous anesthesia technique), exposure controls should be systematically implemented in the following decreasing order of efficacy: engineering controls, administrative controls, work practice controls, and personal protective equipment (PPE). Examples of engineering controls include scavenging systems, dilution ventilation, and key filler devices for filling vaporizers. Examples of administrative controls include training and education, air monitoring and medical surveillance. Examples of work practice controls include use of closed system or low (fresh gas) flow anesthesia, checking for leaks in gas lines, and starting anesthetic gas flow after mask or airway device is applied to patient. Use of higher efficacy controls would preclude the need for PPE when handling liquid anesthetic agents with possible exception of protective gloves.

The primary objective of this study is to describe work practices including use of exposure controls and barriers to using scavenging systems by anesthesia care providers who administer general anesthesia to patients. This national survey is the first to examine adherence to precautionary practices and use of exposure controls including scavenging systems by type of anesthesia care provider and patient (pediatric or adult).

Methods

Survey methodology

The Health and Safety Practices Survey of Healthcare Workers is an anonymous, modular, web-based survey conducted by the National Institute for Occupational Safety and Health (NIOSH) in early 2011. The study population included members of professional practice organizations representing healthcare occupations which routinely use or come in contact with selected hazardous chemicals and drugs. Practices around administration of anesthetic gases were addressed by one of seven hazard modules. 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.[26]

Study population and survey implementation

The survey population for the module on administration of anesthetic gases was targeted to members of three major professional practice organizations representing physician anesthesiologists, nurse anesthetists, and anesthesiologist assistants. These organizations invited members via email which included a link to the survey.

Survey instrument

The web survey included a screening module, core module, and seven hazard modules. If the respondent indicated in the screening module that they had administered anesthetic gases in the past week, they were eligible for the module addressing anesthetic gases. The modular survey was programmed to sequentially present, based on screening questions, the most relevant hazard module, the core module, and a second hazard module, if indicated. Respondents were not presented with more than two hazard modules.

The hazard module addressing administration of anesthetic gases contained 39 questions, 34 of which were targeted to medical (i.e., non-dental) professionals. The format of the questions included multiple choice, Likert scale options, multi-part, yes/no, and numeric. For a few questions where response options were not exhaustive, respondents could mark “other” and type in a response. These were reviewed and determined if they (a) fit into one of the existing categories, (b) were valid other responses, or (c) were unrelated to the question, i.e., general notes about the survey. Responses were

Table 1. Survey instrument topic areas and content of questions.

Topic Area
Training
Frequency (within the past 12 months, more than 12 months ago, never)
Employer procedures
Availability of employer standard procedures to minimize exposure to anesthetic gases
Administration practices
Specific anesthetic gases administered[a]
Anesthetic gases simultaneously administered with nitrous oxide
Number of days administering anesthetic gases in the past 7
Types of work settings where anesthetic gases were administered
Patient receiving anesthetic gases[b]
non-pediatric[c]
pediatric[c]
Engineering controls
Frequency[d] of use of scavenging systems[b]
Reasons for not always using scavenging systems[b]
Most important reason for not using scavenging system[b]
Work practice controls – frequency[d] of use of face mask and/or airway management device[b]
face mask only
face mask followed by airway device
airway device only
Work practice controls – frequency[d] of use of fresh gas flow techniques[b]
high flow anesthesia only
low flow anesthesia only
high followed by low flow anesthesia
closed system anesthesia
Precautionary work practices – frequency[d] of activity[b]
Check anesthesia machine and components for anesthetic gas leaks
Start anesthetic gas flow after face mask or airway device is applied
Stop anesthetic gas flow before turning off carrier gas to breathing system
Post-administration practices
Frequency[d] of patient transfer to recovery area while intubated
Average time spent in patient recovery area (no time, <1 hr, ≥1 hr)
Filling anesthetic gas vaporizers
Whether respondent filled vaporizer during past 7 calendar days
Frequency[d] of use of key-filler system or other closed system
Frequency[d] of use of funnel-fill system
Frequency[d] of filling vaporizer using funnel-fill system in a location where fugitive vapors are controlled
Spills of liquid anesthetic agents
Did any large spills (i.e., contents of one bottle) occur during past 12 months?
Who is responsible for cleanup
Personal and environmental monitoring practices for anesthetic gases
Air monitoring in operating room to detect leaks
Personal exposure monitoring in past 12 months
Was patient recovery area adequately ventilated?

[a]Response options included: desflurane, enflurane, halothane, isoflurane, nitrous oxide, and sevoflurane.
[b]Asked separately for pediatric and non-pediatric patients.
[c]Non-pediatric patient was defined as >13 years of age; pediatric patient was defined as ≤13 years of age.
[d]Response options included: every time, most times, sometimes, rarely, never. Depending on the question, one final response option may have been be included: device not available, not applicable, not applicable, system not available.

recoded, or left as "other" in the case of (b), to reflect this determination.

Most questions sought information for the seven days prior to the survey (hereafter referred to as the past week). Topic areas and content of key practice questions are presented in Table 1. The same questions (n = 7) on exposure controls and precautionary work practices were asked separately of respondents who administered anesthetic gases to adult patients (>13 years of age) and pediatric patients (≤12 years of age), primarily to assess whether there were any differences in the use of exposure control practices.

Data analysis

Data were analyzed using SAS 9.3 (SAS Institute, Inc., Cary, NC). Simple frequencies and prevalences are presented. Because most (>97%) of the non-dental respondents were physician anesthesiologists, nurse anesthetists and anesthesiologist assistants, and worked in hospitals and ambulatory healthcare settings, analyses excluded respondents in other occupations and work settings. Results include responses to selected questions in the core module that describe demographic, employer, and occupation characteristics. This survey was developed to provide descriptive information on practices around administration of anesthetic gases. No *a priori* hypotheses were proposed therefore statistical tests were not done.

Institutional review board

The NIOSH Institutional 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.[27]

Results

Respondent characteristics

A total of 2,987 anesthesia care providers including 1,783 nurse anesthetists, 1,104 physician anesthesiologists, and 100 anesthesiologist assistants completed the hazard module on anesthetic gases. Respondent demographic and employer characteristics are presented for all respondents and by type of anesthesia care provider in Table 2. Respondents are best characterized as follows: mean age of 50 years, 56% were male, 91% were white, 87% had advanced degrees, 43% worked in their profession for ≥20 years, 39% worked for their current employer more than 10 years, 83% worked in hospitals, and 58% worked for an employer with ≥250 employees.

The mean age of nurse anesthetists was 50 years (range: 20–76 years); 56% were female, 95% were white, and 2% were Hispanic. The highest proportion of nurse anesthetists had master's degrees, and worked in their profession and for their current employer for 11–20 years and 1–5 years, respectively. Their employers were best characterized as hospitals, ≥250 employees, for profit, located

Table 2. Respondent characteristics.

Characteristic	All Anesthesia Care Providers (n[a]) %	Nurse Anesthetist (n[a]) %	Physician Anesthesiologist (n[a]) %	Anesthesiologist Assistant (n[a]) %
Sex	(n = 2933)	(n = 1751)	(n = 1083)	(n = 99)
Male	56	44	74	54
Female	44	56	26	46
Race[b]	(n = 2894)	(n = 1733)	(n = 1063)	(n = 98)
White	91	95	85	90
Black	3	3	2	3
Asian	6	2	13	7
Other	1	1	1	1
Ethnicity	(n = 2921)	(n = 1745)	(n = 1078)	(n = 98)
Hispanic	2	2	4	2
Age (years)	(n = 2880)[c]	(n = 1728)[c]	(n = 1054)[c]	(n = 98)
20–24	<1	<1	<1	1
25–34	9	9	9	31
35–44	20	22	16	38
45–54	31	29	35	19
55–64	34	35	33	10
>64	6	6	7	1
Education	(n = 2928)[c]	(n = 1745)[c]	(n = 1084)[c]	(n = 99)
≤Associate's degree	4	6	0	0
Bachelor's degree	10	16	0	5
Master's degree	47	74	<1	94
Medical or doctoral degree/Plus	40	4	100	1
Time in Current Occupation[c]	(n = 2972)[c]	(n = 1774)[c]	(n = 1098)	(n = 100)
<1 year	2	2	2	6
1–5 years	16	18	10	27
6–10 years	13	14	12	20
11–20 years	25	26	25	25
21–30 years	26	20	36	11
>30 years	17	19	15	11
Time with Current Employer	(n = 2982)	(n = 1781)[c]	(n = 1101)	(n = 100)
<1 year	7	7	6	14
1–5 years	32	35	28	41
6–10 years	22	23	20	23
11–20 years	21	20	23	13
>20 years	18	14	23	9
Member of a Labor Union	(n = 2940)	(n = 1754)	(n = 1087)	(n = 99)
Yes	3	4	2	0
Employer Industry Category[c,d]	(n = 2987)	(n = 1783)	(n = 1104)	(n = 100)
Ambulatory healthcare services	17	16	20	9
Hospital	83	84	80	91
Size of Employer (number of employees)	(n = 2963)[c]	(n = 1768)[c]	(n = 1096)	(n = 99)[c]
1 (i.e., only myself)	1	2	1	0
2–9	5	7	3	3
10–99	23	24	22	26
100–249	12	14	9	10
250–1,000	26	26	28	15
>1,000	32	28	37	45
Employer Ownership Type	(n = 2943)	(n = 1755)	(n = 1092)	(n = 96)
For profit	53	53	54	51
Non-profit	34	35	32	35
City, county, district, state gov't	10	8	12	14
Federal gov't (e.g., VHA)	3	4	2	0
Employer Regional Location[e]	(n = 2938)[c]	(n = 1755)[c]	(n = 1084)[c]	(n = 99)[c]
Northeast	19	17	24	1
Midwest	25	28	20	34
South	38	42	29	61
West	17	13	26	4
Employer Location by Population Density	(n = 2971)[c]	(n = 1772)[c]	(n = 1099)	(n = 100)
Large city (≥50,000 people)	61	54	70	76
Small city (<50,000 people)	20	22	16	14
Suburbs	11	11	10	8
Rural areas (e.g. farms, ranches, small towns, and unpopulated regions)	9	13	4	2

VHA=Veterans Health Administration

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

[b]Percents may add to more than 100 percent because respondents could select more than one answer.

[c]Percents may not add up to exactly 100 percent due to rounding.

[d]Industry categories based on North American Industry Classification System (NAICS).

[e]Northeast: Connecticut, Maine, Massachusetts, New Jersey, New Hampshire, New York, Pennsylvania, Rhode Island, and Vermont; Midwest: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin; South: Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia; West: Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

in large cities, and mainly in the south. Four percent were members of labor unions.

The mean age of physician anesthesiologists was 51 years (range 23–76 years). They possessed many of the same characteristics as the nurse anesthetists with the exception that a higher proportion (74%) were male and non-White (13% Asian and 4% Hispanic). All possessed doctoral degrees or higher education, worked in their profession for 20–30 years, and 2% belonged to labor unions. Anesthesiologist assistants also possessed many of the same characteristics as the nurse anesthetists with the exception that they were the youngest of the three groups with a mean age of 41 years (range: 24–69 years); 54% were male, 90% were white, 94% had a master's degree, and the highest proportion worked in their profession for 1–5 years.

Training and availability of employer procedures

18% of respondents reported that they had never received training on safe handling of anesthetic gases. The proportion of physician anesthesiologists (28%) who never received such training was over twice that of nurse anesthetists (13%) and three times that of anesthesiologist assistants (9%). Of the respondents who had received training, most (81%; range: 77–81%) reported it had been more than 12 months ago.

Only half (54%) of respondents reported that standard procedures to minimize exposure to anesthetic gases were available from their employer, and over a quarter (27%) reported that they did not know whether such procedures were available. Responses were comparable among the three groups. Approximately half (57%) of nurse anesthetists and even fewer physician anesthesiologists (49%) and anesthesiologist assistants (45%) reported that procedures were available, with about 30% of each group reporting that they did not know if they were.

Anesthetic gas administration practices

Anesthetic gas administration practices are presented in Table 3. Respondent practices can best be characterized as follows: 70% administered for more than 10 years; 40% for 5 of the past 7 days, and 86% administered them in hospital operating rooms. Nearly all (99%) administered to adult patients and about half (47%) reported that they also administered to pediatric patients during the past week. When asked to select from a list of all inhaled anesthetics administered during the past week, most respondents (96%) reported sevoflurane, followed by desflurane (69%), nitrous oxide (64%), and isoflurane (36%). Use of halothane and enflurane was negligible. When respondents were asked to select the anesthetic gas most often administered in the past week, 62% reported sevoflurane, followed by desflurane (27%), isoflurane (8%) and nitrous oxide (4%). Most respondents (95%) reported that they simultaneously administered nitrous oxide in combination with halogenated anesthetics, primarily sevoflurane (73%) and, to a lesser extent, desflurane (16%) and isoflurane (11%). Administration practices were similar among respondents with the following exceptions: physician anesthesiologists administered anesthetic gases for the most years and least number of days per week; and anesthesiologist assistants administered anesthetic gases for the fewest number of years, most days per week, and used nitrous oxide the most among all respondents.

Exposure controls

Waste gas scavenging system

On average, 97% of respondents reported that a waste anesthetic gas scavenging system was used "every time" they administered anesthetic gases during the past week (Table 4). Responses were similar among the three groups and for adult and pediatric patients. Of the respondents who reported not using scavenging systems every time during administration to adult and pediatric patients, most reported that it was because they were unavailable or not working.

Precautionary practices

Respondents were asked how often (i.e., every time, most times, sometimes, rarely, never) they utilized selected precautionary practices as part of their routine for administering anesthetic gases to adult and pediatric patients. These practices included: (1) checking delivery system for anesthetic gas leaks (practice #1); (2) starting anesthetic gas flow after delivery mask or airway mask was applied to patient (practice #2); and (3) turning off anesthetic gas flow before carrier gas to the breathing system was turned off (Table 4). Adherence to these recommended practices was evaluated by combining the percent of respondents performing each practice "every time" and "most times." On average, most respondents were compliant with practice #1 and least compliant with practice #2. Percent adherence was similar by occupation and patient type for each practice, with the exception of practice #2 for pediatric patients where, on average, it was markedly lower (65% vs. 86%) and more variable among respondent groups (range of 14% vs. 4%) when compared to adult patients.

Use of fresh gas flow techniques

Respondents were also asked how often (same five response options as described above) they implemented

Table 3. Anesthetic gases administration practices of respondents.

Administration Practices (in the past week unless otherwise noted)	All Anesthesia Care Providers (n[a]) %	Nurse Anesthetist (n[a]) %	Physician Anesthesiologist (n[a]) %	Anesthesiologist Assistant (n[a]) %
No. of years (in career) administering anesthetic gases[b]	(n = 2978)[b]	(n = 1777)[b]	(n = 1102)	(n = 99)[b]
<1 year	<1	<1	1	0
1–5 years	14	16	8	30
6–10 years	15	16	14	20
11–20 years	25	26	24	27
> 20 years	45	42	53	22
No. of days administering anesthetic gases	(n = 2986)[b]	(n = 1782)	(n = 1104)	(n = 100)
1 day	6	3	10	3
2 days	9	7	13	4
3 days	16	16	15	15
4 days	20	23	17	16
5 days	40	42	34	52
6–7 days	10	9	11	10
Anesthetic gases administered[c]	(n = 2987)	(n = 1783)	(n = 1104)	(n = 100)
Sevoflurane	96	96	96	98
Desflurane	69	72	66	65
Nitrous oxide	64	64	63	86
Isoflurane	36	34	39	45
Anesthetic gases administered most often	(n = 2984)[b]	(n = 1782)	(n = 1102)[b]	(n = 100)
Sevoflurane	62	60	64	62
Desflurane	27	29	23	21
Isoflurane	8	7	9	7
Nitrous oxide	4	3	6	10
Simultaneous administration of nitrous oxide with any of the halogenated anesthetic gases	(n = 1927)	(n = 1144)	(n = 697)	(n = 86)
Yes	95	94	96	97
Anesthetic gases most often administered with nitrous oxide	(n = 1829)	(n = 1075)[b]	(n = 671)[b]	(n = 83)
Sevoflurane	73	71	76	72
Desflurane	16	18	12	17
Isoflurane	11	11	11	11
Anesthetic gases administered to patients 13 years or older (i.e., non-pediatric or adult patients)	(n = 2987)	(n = 1783)	(n = 1103)	(n = 100)
Yes	99	100	98	97
Anesthetic gases administered to patients 12 years or younger (i.e., pediatric patients)?	(n = 2986)	(n = 1782)	(n = 1104)	(n = 100)
Yes	47	46	49	47
Location(s) where anesthetic gases were most often administered in the past week	(n = 2986)	(n = 1783)	(n = 1104)	(n = 100)
Hospital OR	86	86	85	92
Outpatient surgical center	12	12	11	7
Other	2	2	4	1

[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.
[c]Percents may add to more than 100% because respondents could select more than one answer.

commonly used fresh gas flow techniques for delivering anesthetic gases to adult and pediatric patients. In order of most to least effective in minimizing exposure to waste anesthetic gases, these practices included: (1) closed-system anesthesia; (2) low flow anesthesia only (on average <3 L/min of fresh gas); (3) high flow followed by low flow anesthesia; and (4) high flow anesthesia only (on average 3–6 L/min of fresh gas) (Table 4). Again, we evaluated use of these practices by combining the percent of respondents performing each practice "every time" and "most times." On average, most respondents reported practice #3, which was more prevalent for pediatric (72%) vs. adult patients (58%). Practices #1 and #2 were less common, particularly for pediatric patients. Practice #4 was the least common delivery technique, used by 17% and 6% of respondents for pediatric and adult patients, respectively. Nurse anesthetists had the highest proportion of use of closed-system and low flow only delivery techniques for adult and pediatric patients when compared to the other anesthetists.

Use of face mask and airway device

Respondents were also asked how often (same response options as described above) they used a face mask and/or airway device when administering anesthetic gases to adult and pediatric patients. In order of most to least desirable in terms of minimizing waste gas emissions and risk of exposure, these included: (1) airway device only, (2) face mask followed by an airway device, and (3) face mask only (Table 4). To evaluate the extent of use of these devices, we combined the percent of respondents using these devices "every time" and "most times." A face mask

Table 4. Scavenging systems, administrative controls, and work practices for administering anesthetic gases to adult and pediatric patients.

Type of Exposure Control	All Anesthesia Care Providers	Nurse Anesthetists	Physician Anesthesiologists	Anesthesiologist Assistants	All Anesthesia Care Providers	Nurse Anesthetists	Physician Anesthesiologists	Anesthesiologist Assistants
	Percent Reporting Every Time[a] (n[b])							
Engineering Control	Adult Patients				Pediatric Patients			
How often was a waste gas scavenging system used when you administered anesthetic gases to patients?	97 (n = 2940)	98 (n = 1759)	96 (n = 1084)	99 (n = 97)	97 (n = 1394)	98 (n = 808)	96 (n = 539)	96 (n = 47)
	Percent Reporting Every Time/Most Times[a] (n[b])							
Administrative Controls	Adult Patients				Pediatric Patients			
When administering anesthesia gas to patients during the past 7 calendar days, how often did you …								
(1) check anesthesia machine, breathing circuit, vaporizer and other components for leaks?[c]	95 (n = 2879)	97 (n = 1755)	92 (n = 1029)	96 (n = 95)	96 (n = 1361)	98 (n = 803)	95 (n = 512)	96 (n = 46)
(2) start anesthetic gas flow after delivery mask or airway mask is applied to patient?[c]	86 (n = 2943)	88 (n = 1767)	84 (n = 1080)	84 (n = 96)	65 (n = 1393)	69 (n = 809)	61 (n = 537)	55 (n = 47)
(3) turn off anesthetic gas flow before carrier gas to the breathing system is shut off?[c]	94 (n = 2940)	95 (n = 1766)	93 (n = 1077)	95 (n = 97)	91 (n = 1393)	94 (n = 810)	88 (n = 536)	91 (n = 47)
	Percent Reporting Every Time/Most Times[a] (n[b])							
Work Practice – Use of Closed System and Fresh Gas Flow Delivery Technique	Adult Patients				Pediatric Patients			
When administering anesthesia gas to patients during the past 7 calendar days, how often did you use …								
(1) closed-system anesthesia?[d]	33 (n = 2669)	42 (n = 1584)	22 (n = 984)	11 (n = 91)	29 (n = 1257)	37 (n = 722)	18 (n = 491)	9 (n = 44)
(2) low flow anesthesia only (on average less than 3L/min of fresh gas)?	51 (n = 2903)	56 (n = 1738)	42 (n = 1069)	51 (n = 96)	21 (n = 1373)	23 (n = 798)	18 (n = 528)	21 (n = 47)
(3) high flow followed by low flow anesthesia?	58 (n = 2934)	53 (n = 1759)	66 (n = 1078)	59 (n = 97)	72 (n = 1395)	68 (n = 809)	77 (n = 539)	77 (n = 47)
(4) high flow anesthesia only (on average 3-6 L/min of fresh gas)?	6 (n = 2890)	7 (n = 1734)	6 (n = 1060)	2 (n = 96)	17 (n = 1370)	20 (n = 797)	12 (n = 526)	11 (n = 47)
	Percent Reporting Every Time/Most Times[a] (n[b])							
Work Practice – Use of Patient Face Mask and Airway Device[e]	Adult Patients				Pediatric Patients			
When administering anesthesia gas to patients during the past 7 calendar days, how often did you use …								
(1) an airway device only?[d]	28 (n = 2838)	30 (n = 1699)	26 (n = 1043)	24 (n = 96)	6 (n = 1351)	7 (n = 785)	5 (n = 519)	2 (n = 47)
(2) a face mask followed by airway device?[d]	74 (n = 2904)	73 (n = 1732)	75 (n = 1076)	75 (n = 96)	70 (n = 1394)	67 (n = 808)	74 (n = 540)	70 (n = 46)
(3) a face mask only?[d]	5 (n = 2873)	5 (n = 1724)	4 (n = 1053)	2 (n = 96)	11 (n = 1370)	12 (n = 794)	8 (n = 529)	4 (n = 47)

[a]Respondents were asked to select from the following response options: every time, most times, sometimes, rarely or never. Some of the questions include "not available" or "not applicable" as additional response options.
[b]Total number of respondents varies for individual items (i.e., number of eligible respondents less number who elected not to answer and excluded respondents where the activity was not applicable to them).
[c]Excludes respondents who reported "not applicable" (i.e., others were responsible for this work practice).
[d]Excludes respondents who reported that this technique or device was not available.
[e]Examples of airway devices include endotracheal tube, tracheostomy tube and laryngeal mask airway (LMA).

followed by an airway device was used every time/most times by the highest proportion of respondents, and by about the same proportion of respondents for adult (74%) and pediatric (70%) patients. By comparison, an airway device only was used by nearly five times as many respondents for adult (28%) vs. pediatric (6%) patients, and a face mask only was used by more than twice as many respondents for pediatric (11%) vs. adult (5%) patients.

Filling vaporizers and spills of liquid anesthetic agents

Overall, 84% of respondents reported that they personally filled vaporizers with liquid anesthetic agents during the past week. Filling of vaporizers was reported by most anesthesiologist assistants (92%) and nurse anesthetists (91%) and, to a lesser extent, by physician anesthesiologists (73%) (Table 5). Most (86%) of the respondents who filled vaporizers reported using a key-filler or other closed system technique "every time" or "most times." The key-filler system, which is a closed system that prevents escape of anesthetic vapors, was used by a higher proportion of nurse anesthetists (86%) and physician anesthesiologists (87%) as compared to anesthesiologist assistants (79%). Use of a funnel-fill system every or most times was reported by 17% of respondents. This "open-air" technique was used by a higher proportion of nurse anesthetists (19%) and anesthesiologist assistants (18%) compared to physician anesthesiologists (11%). Only 7% of respondents who used a funnel-fill system reported filling vaporizers in a location where fugitive vapors are controlled (e.g., ventilated enclosure).

One hundred thirteen respondents (5%) reported that a large spill (i.e., contents of a bottle of liquid anesthetic agent) had occurred during the past 12 months while filling or draining vaporizers. A higher proportion of physician anesthesiologists and nurse anesthetists reported spills compared to anesthesiologist assistants. Over half (56%) of respondents reported that the spills were cleaned-up by: (1) the person causing the spill whether trained (20%) or not (37%); (2) a designated spill response team (8%); or (3) by others (4%) where "anesthesia technician" was the most common write-in response. One third (32%) reported that they did not know who cleaned up the spill. Several respondents used the "other" response category to type-in that most spills had evaporated before they could be cleaned-up.

Work practices and self-assessment of general ventilation in the post-anesthesia patient recovery area

Nearly all (97%) respondents reported that they spent time with patients in the post-anesthesia patient recovery area. Of these respondents, 78% spent less than one hour and 19% spent 1 hr or more in this area. Over half (54%) of respondents reported that the recovery area was adequately ventilated, and 42% did not know. A very small

Table 5. Anesthesia vaporizer filling practices and spills associated with filling and draining vaporizers.

Filling Practices/Spills	All Anesthesia Care Providers		Nurse Anesthetists		Physician Anesthesiologists		Anesthesiologist Assistants	
Did you personally fill anesthesia vaporizers during the past week?	n[a] 2968	%[b] 84	n[a] 1767	%[b] 91	n[a] 1101	%[b] 73	n[a] 100	%[b] 92
When filling anesthesia vaporizers, how often did you use …	n[a]	%[c]	n[a]	%[c]	n[a]	%[c]	n[a]	%[c]
a "key-filler" or other closed system[d]	2434	86	1559	86	784	87	91	79
a "funnel-fill" system (also called "pour-fill" or "screw cap fill" systems)[d]	2034	17	1280	19	677	11	77	18
How often did you fill the vaporizer (using the funnel-fill system) in a location where fugitive vapors are controlled (e.g., ventilated enclosure)?	n[a] 759	%[c] 7	n[a] 495	%[c] 7	n[a] 230	%[c] 9	n[a] 34	%[c] 0
In the past 12 months, did any large spills[e] of liquid anesthetic agent(s) occur during filling or draining of vaporizers?	n[a] 2500	%[b] 5	n[a] 1606	%[b] 4	n[a] 802	%[b] 5	n[a] 92	%[b] 2

[a]Total number of respondents; varies for individual items (i.e., number of eligible respondents less number who elected not to answer).
[b]Percent reporting Yes.
[c]Percent reporting Everytime/Most times. Respondents were asked to select from the following response options: every time, most times, sometimes, rarely or never. Some of the questions included "not available" or "not applicable" as additional response options.
[d]Excludes respondents who reported that system was not available.
[e]Defined in the survey as the contents of one bottle of liquid anesthetic agent.

Table 6. Work practices and self-assessment of general ventilation in the post anesthesia patient recovery area.

Practice/Self-Assessment	All Anesthesia Care Providers		Nurse Anesthetists		Physician Anesthesiologists		Anesthesiologist Assistants	
What was the average amount of time you spent each work day with patients in recovery area(s)?	n[a] 2986	%	n[a] 1782	%[b]	n[a] 1104	%[b]	n[a] 100	%
No time spent in recovery area		3		4		1		0
<1 hr		78		83		68		92
≥1 hr		19		13		30		8
Was the patient recovery area where you spent the most time during the past week adequately ventilated?	n[a] 2889	%	n[a] 1701	%	n[a] 1088	%[b]	n[a] 100	%
Yes		54		53		55		48
No		4		5		4		2
I don't know		42		42		50		50
How often was the patient transferred to recovery area while intubated?	n[a] 2812	%[c] 1	n[a] 1675	%[c] 1	n[a] 1044	%[c] 2	n[a] 93	%[c] 0

[a]Total number of respondents; varies 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.
[c]Percent of respondents reporting Everytime/Most times. Respondents were asked to select from the following response options: every time, most times, sometimes, rarely or never. Some of the questions included "not available" or "not applicable" as additional response options.

proportion of respondents reported that patients were intubated (i.e., on mechanical ventilation) when transferred to the recovery area (Table 6).

Ambient air and exposure monitoring for anesthetic gases

Air monitoring for detecting anesthetic gas leaks was twice as common as personal exposure monitoring. Thirty percent of respondents reported that air monitoring had been conducted on a continuous or periodic basis in the operating room to detect anesthetic gas leaks whereas only 15% of respondents reported that exposure monitoring had been conducted during the past year to assess personal or co-worker exposure to anesthetic gases (Table 7). A markedly lower proportion of anesthesiologist assistants reported that air monitoring had been conducted compared to the other practitioners.

Discussion

Exposure to waste anesthetic gases can result from a variety of causes: ineffective or no waste gas scavenging system; improper or inadequate maintenance of anesthesia machine; leaks from gas lines and other components; poor work practices or facility guidelines (e.g., high flow anesthesia); and ineffective general ventilation in the operating room and recovery areas. In our survey we found nearly universal use of waste gas scavenging systems. This finding was not unexpected since all anesthesia machines sold in the U.S. since the late 1990's have been equipped with these devices.[23] Furthermore, waste anesthetic gas scavenging is required by The Joint Commission[28] and is recommended by ASA, AANA, NIOSH, and OSHA.[16,20–24] We did find that the following precautionary work practices were not always implemented: performing leak checks of the anesthesia machine and components; starting anesthetic gas flow after face mask or airway device is applied to patient; and shutting off anesthetic gas flow before carrier gas to the breathing system is shut off. Additionally, closed-system or low flow only techniques were not always used and exclusive use of a face mask was reported for some patients which, if lacking a good face seal, may increase exposure risk of healthcare personnel.

We also found funnel-fill, "open-air" systems were being used by about one of every six respondents. These systems, found in some older vaporizers,[29] increase anesthetic gas exposure risk from evaporation of the liquid anesthetic agent during manual pouring and from spills. The exposure risk would be increased in instances where vaporizers are filled using the funnel-fill system in locations where fugitive vapors were not controlled.

Some respondents also reported that large spills of liquid anesthetic agents had occurred during the past year while filling or draining vaporizers. Over a third of respondents reported that spills were cleaned-up by untrained staff. Also of concern, some reported that it was not uncommon for spills to evaporate before they are cleaned up which represents another source of exposure to healthcare personnel in areas where spills occur.

Use of exposure control practices varied by type of patient (adult or pediatric) and anesthesia care providers. For those respondents who administered anesthetic gases to pediatric patients, we found lower adherence to work practices which minimize exposure to waste anesthetic gases: starting anesthetic gas flow after face mask or airway mask is applied to patient, use of closed-system anesthesia or low flow only anesthesia, and use of an airway

Table 7. Ambient air and worker exposure monitoring practices for anesthetic gases.

Air Monitoring Practices	All Anesthesia Care Providers		Nurse Anesthetists		Physician Anesthesiologists		Anesthesiologist Assistants	
Has air monitoring for anesthetic gases been conducted on a continuous or periodic basis in the operating room to detect anesthetic gas leaks?	n[a] 2967	% Yes 30	n[a] 1766	% Yes 29	n[a] 1101	% Yes 32	n[a] 100	% Yes 17
Has exposure monitoring (using badges or other air sampling devices) been conducted in the past 12 months to assess your exposure or your co-workers' exposure to anesthetic gases?	n[a] 2984	% Yes 15	n[a] 1780	% Yes 16	n[a] 1104	% Yes 13	n[a] 100	% Yes 16

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

device alone or immediately following face mask induction. Checking for leaks and judicious starting/stopping of anesthetic gas flows are precautionary practices that should always be followed. The other surveyed practices (anesthetic gas flow delivery technique and delivery devices) are usually utilized on a case-by-case basis depending on the patient's medical condition. Adherence to precautionary work practices and closed-system or low fresh gas flow techniques was generally highest among nurse anesthetists.

Nearly all respondents reported that anesthetized patients were extubated in the operating room or surgical suite before they were transferred to the recovery area. Because the extubated patients' off-gas anesthetic gases in their breath, they represent a potential source of exposure to anesthesia care providers who reported that they spent time with patients in the post-anesthesia recovery area. Only a small proportion of respondents reported that the general ventilation in the recovery area was inadequate, although nearly half reported that they did not know. Room ventilation, proximity to the patient, and time spent in the recovery area are exposure risk factors. Another method to minimize waste anesthetic gases in the recovery room is to provide patients with face masks that simultaneously scavenge waste anesthetic gases and deliver oxygen. Information on whether these devices were used was not obtained during this survey and should be assessed in future studies.

Nearly one of every five respondents had not received training addressing safe handling of anesthetic agents, including more than a quarter of physician anesthesiologists. Of those who had received training, 6–7 of every 10 respondents reported that the training was more than a year ago. Training and education are fundamental administrative controls, recommended upon initial job assignment or whenever a new chemical or process is introduced.[30] Although annual refresher training is not required, this would increase the likelihood that precautionary measures become second nature among all healthcare personnel who have likely exposure to waste anesthetic gases.

Air monitoring to assess leaks in the operating room anesthesia delivery equipment was reported by only 30% of respondents and was more common than personal exposure monitoring of anesthesia care providers, reported by 16% of respondents. Routine air monitoring for waste anesthetic gases is recommended by NIOSH, OSHA, and AANA; however, the American Society of Anesthesiologists (ASA) considers proper maintenance and inspection of anesthesia machines to be a more effective strategy to minimize waste gas emissions.

Several limitations apply to this survey. Since the survey sample was targeted to members of professional practice organizations, findings reflect the experiences and practices of the respondents and are not generalizable to all healthcare workers or to all members of each of the participating professional organizations. Availability of the survey only to members with email addresses and internet access was another limitation. Survey participants who have resources to belong to a professional organization may be more likely to be further along in their career, better paid, more educated, and more aware of health and safety issues. A response rate cannot be calculated because the invitation email specified the chemical agents under study, including anesthetic gases, and that eligibility was based on whether or not invitees had used anesthetic gases on the job; it is unknown who decided not to participate because they did not use anesthetic gases versus those who used them but decided not to participate for other reasons. Finally, survey data are self-reported and not validated by observation or other means.

Information on the effectiveness of waste gas scavenging systems, types of PPE used during spill cleanup and filling/draining vaporizers, and availability of and participation in a medical surveillance program, was not collected in this study and should be evaluated in future studies. The nearly universal use of scavenging systems is noteworthy and may be associated with The Joint Commission's requirement that all waste anesthetic gases and vapors be scavenged using active scavenging methods.

Conclusion

This national survey is the first to examine use of engineering, administrative, and work practice controls for anesthetic gases by physician anesthesiologists, nurse anesthetists, and anesthesiologist assistants who primarily work in hospitals. Successful management of waste anesthetic gases should include scavenging systems, hazard awareness training, availability of standard procedures to minimize exposure, regular inspection of anesthesia delivery equipment for leaks, periodic air and exposure monitoring, prompt elimination of spills and leaks, and medical surveillance.

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