IV. ENVIRONMENTAL DATA AND BIOLOGIC EVALUATION OF EXPOSURE

Inhalation Anesthesia Techniques and Sources of Waste Anesthetic Gases

The principal source of waste anesthetic gases in the unscavenged operating room is the intentional outflow or discharge from the anesthetic breathing circuit. The magnitude of this source depends on a number of variables, the major ones being the breathing circuit used to administer the gases and the flow rates and concentrations of the gases used. After effective scavenging techniques have been applied, other sources of leaks from the anesthesia equipment and anesthetist work practices are considered to be primary sources of waste anesthetic gases.

Inhalation anesthetic breathing circuits can be divided into those that absorb carbon dioxide exhaled by the patient and those that do not [1,158]. These two major classes are further subdivided based on the physical characteristics of the breathing circuits, such as rebreathing and access of the pulmonary system to the atmosphere. The breathing system classes are outlined in Table XIII-6.

In systems without carbon dioxide absorption, the open drop and insufflation techniques are the most difficult to control from a waste gases standpoint. In the open drop method, a volatile anesthetic agent is dropped onto the surface of a gauze-covered metal mask where the agent is volatilized, diluted, and drawn into the lungs of the patient on inhalation. With the insufflation technique, an anesthetic mixture is introduced into the patient's naso- or oropharynx and delivery is completed upon inhalation. High gas flow rates are often required because of dilution of the anesthtic agent by room air.

The Mapleson-type systems are represented by a number of breathing circuits, the most common being the Magill and Ayre's T-piece. The Magill system provides the patient with fresh gases and the expired gases pass out of an expiratory valve. If the patient's respiration is spontaneous and an adequate amount of fresh gas is supplied, the Magill system could be regarded as a nonrebreathing system.

The T-tube apparatus has its greatest application in pediatric anesthesia, since circuit resistance and dead space are minimal. Gases from an anesthetic gas machine flow into a T, where they are inhaled through one branch and exhaled through the other. Rebreathing is reduced by a high flow of gases. The system has been modified (Summer's modification) to include a reservoir bag for assisted inspiration and partial rebreathing. Although this technique discharges all exhaled gases to the atmosphere at flows of 3-10 liters/minute, efficient scavenging methods have been developed. Nonrebreathing or nonreturn systems deliver only fresh gas to the patient during inspiration and are equipped with a nonreturn valve. Self-administration of an anesthetic agent is a common practice in hospital labor rooms and makes use of a nonrebreathing system.

The group of breathing circuits that have carbon dioxide absorption include the to-and-fro system and the circle system, both of which deliver exhaled gases from the patient to a soda-lime absorber for carbon dioxide absorption and back to the patient. In the circle system, the gases are passed through tubing before being returned to the patient. Both the circle and to-and-fro systems are used in a closed or semiclosed manner, depending on whether the expiration valve is closed or open. The absorption system's disadvantage is that, at low flow rates of fresh gases, it is difficult to determine the concentrations of anesthetic and oxygen being delivered to the patient. However, the majority of inhalation anesthesia is administered by a semiclosed, circle carbon dioxide absorption system.

All of the breathing systems described above require the use of numerous components such as valves, connections, and tubing which are potential sources of gas leakage if not properly maintained and tightly connected. Ill-fitting face masks and improperly inflated endotracheal tube cuffs are significant leak sources. Mechanical ventilators, which are frequently used during prolonged surgical procedures to assist respiration, are also major leak sources which must be controlled. Finally, the waste anesthetic gas scavenging system itself, if improperly designed, installed, or maintained, may be a source of gas leakage [159].

Environmental Concentrations and Sampling and Analysis Methods

Analytical methods used to determine concentrations of anesthetic gases and vapors have included the manometric method of Van Slyke and Neill [160,161], the combustion method of Hirsch and Kappus [19], several gas chromatographic methods [162-166], and several infrared spectrophotometric methods [167-169]. Gas chromatographic and infrared analyses are the two major analytical methods used in the reporting of environmental concentrations presented below.

(a) Without Anesthetic Gas Scavenging

Anesthetic gas concentrations in rooms not equipped with gas scavenging may be influenced by a number of factors including the types and concentrations of anesthetic gases used, type of anesthetic breathing system, method of anesthetic administration (face mask versus endotracheal tube), room air movement, and operating room configuration.

The first quantitative data on the concentration of inhalation anesthetic agents in operating room air were published by Hirsch and Kappus [19] in 1929. The investigators used a combustion method which they had developed to measure the levels of ether in several operating rooms during surgical procedures. Measured air samples were burned over incandescent copper oxide and the quantity of carbonic acid produced was determined titrimetrically. Ether levels ranged from 10 to 100 ppm prior to any attempt to remove the waste ether vapor.

Detailed measurements of occupational exposure of operating room personnel to anesthetic gases were reported by Linde and Bruce [131] in 1969. In their study, 104 air samples from 21 operating rooms were collected by drawing air into glass syringes with subsequent analysis using gas chromatography (minimum detectable limit: 20 ppm nitrous oxide, 0.5 ppm halothane). Nitrous oxide and halothane were administered during the surgical cases sampled, with the anesthesic machine discharge valve usually in the open position. These investigators found peak concentrations of 27 ppm halothane and 428 ppm nitrous oxide. The overall average concentrations of all measurements in all operating rooms sampled were 130 ppm nitrous oxide and 10 ppm halothane. Anesthetic gas concentrations were found to be fairly uniform throughout the rooms sampled.

In 1970, Askrog and Peterson [132] reported average concentrations of 85 ppm halothane and 7,000 ppm nitrous oxide in the breathing zone of anesthesiologists when a nonrebreathing system was used. Also in 1970, Hallen et al [133] reported measurements of halothane in the operating room in which nonrebreathing techniques with a face mask were used during all measurements. Total anesthetic gas flows ranged from 5 to 6 liters/minute with 0.25-1.5 vol% halothane. Breathing zone samples were collected in polyvinylidene chloride sample bags and analyzed by gas chromatography using a flame ionization detector (minimum detectable limits were not given). These researchers found halothane concentrations of 0-28 ppm at distances greater than 25 cm from the gas discharge point (probably representative of anesthetist exposures) with a mean of 8.0 ppm. Values as high as 290 ppm of halothane were found near the gas discharge point. These investigators found a relatively uniform distribution of halothane throughout the operating room.

In 1971, Corbett and Ball [134] reported levels of methoxyflurane ranging from 2 to 10 ppm in the breathing zone of anesthetists and 1-2 ppm in the breathing zone of surgeons. Studies of halothane exposures showed similar concentrations as those found for methoxyflurane for both anesthetists and surgeons. The investigators also measured nitrous oxide exposures and found values ranging from 330 to 9,700 ppm in the breathing zone of the anesthetists and 310 to 550 ppm near the surgeons.

Corbett et al [135] also measured exposures of operating room personnel to trichloroethylene. With a nonrebreathing system administering trichloroethylene at 0.25-1.0% with a flow of 9 liters/minute in an operating room equipped with a nonrecirculating air-conditioning system, the concentrations in the vicinity of the surgeons ranged from 0.3 to 1.5 ppm. All samples were collected in glass syringes and analyzed by gas chromatography using a flame ionization detector (minimum detectable concentrations: 10 ppb).

Whitcher et al [136] noted halothane levels present in the operating room during the use of both nonrebreathing (10 liters/minute) and semiclosed circle (4-5 liters/minute) anesthesia systems using 1% halothane. Atmospheric samples were collected through polyethylene tubing at nine different locations reflecting concentrations in the vicinity of the anesthesia machine (ie, anesthetist's exposure) and at four distant positions representative of other operating room personnel exposures. Samples were analyzed using a quadripole mass spectrometer. Concentrations of halothane in the vicinity of the gas machine averaged 8.69 ppm (SE $\pm$ 0.91 ppm) using a nonrebreathing system and 4.93 ppm (SE $\pm$ 0.96 ppm) using a semiclosed circle system. Nonrecirculating air-conditioning systems were used in all operating rooms sampled.

Nikki et al [137] presented the results of measurements of halothane and nitrous oxide in six operating rooms and in three recovery rooms where trace anesthetic gases were exhaled by patients. Samples were collected during consecutive 30-minute periods by slowly filling a plastic sample bag and subsequently analyzed by gas chromatography. A flame ionization detector was used for halothane and an electron capture detector for nitrous oxide. Sample locations were chosen to reflect the anesthetist and recovery room personnel exposures. Anesthetic gas flow rates ranged from 4 to 10 liters/minute with 70 vol% nitrous oxide and 0.5 to 1.5 vol% halothane. Sample results in the operating room showed a mean concentration of 13.85 ppm for halothane (SD 10.43 ppm) and 929 ppm for nitrous oxide (SD 659 ppm). Uniform gas distribution within the operating room was observed. In the recovery rooms, halothane concentrations averaged 2.77 ppm (SD 1.42 ppm) and nitrous oxide averaged 146 ppm (SD 115 ppm). It must be noted that concentrations measured in the recovery rooms may have been elevated because of their proximity to the operating rooms. In addition, recovery rooms had little air movement (0.2-1.2 air changes/hour). The operating room tested also had very low air exchange rates, with none greater than 3 changes/hour.

Pfaffli et al [138] also reported results of measurements of halothane and nitrous oxide in unscavenged operating rooms and in recovery rooms using the same sampling and analysis techniques described above by Nikki et al [137]. Halothane concentrations in the operating rooms ranged from 2.1 to 57 ppm with a mean of 10.9 ppm, while nitrous oxide ranged from 60 to 4,900 ppm with a mean of 1,080 ppm. Recovery room concentrations of halothane were found to range from 0.9 to 8.2 ppm with a mean of 3.0 ppm and nitrous oxide ranged from 20 to 1,600 ppm with a mean of 305 ppm. All operating rooms and recovery areas had minimal air exchange rates.

Bruce and Linde [139] published the results of an extensive study of halothane in recovery room air. Patients in two recovery rooms after halothane anesthesia of at least 1 hour were studied by collecting samples 24 inches from their heads every 15 minutes for 1 hour. Samples were collected in gastight glass syringes and analyzed by gas chromatography with a flame ionization detector (minimum detectable concentration: 0.1 ppm). Five minutes after completion of surgery, concentrations averaged 0.36 ppm in one recovery room and 0.61 ppm in the other room. After 1 hour, no halothane was detected in one recovery room; however, concentrations in the other room averaged 0.32 ppm. No recovery room ventilation data are given in this report.

Gotell and Sundell [140] took halothane concentration measurements in the breathing zones of six nurse-anesthetists in five different operating rooms. Personnel samples were taken using activated charcoal tubes followed by halothane analysis by gas chromatography. TWA halothane exposures ranged from 14 to 59 ppm. The authors noted that halothane concentrations in expired air samples of these six subjects taken 15 minutes, 6 hours, and 16 hours after the end of anesthesia were directly proportional to the extent of exposure.

Usubiaga et al [141] reported results of halothane concentration measurements in operating rooms and in nearby rooms. Samples were collected near the face of the anesthetist using 10-ml airtight glass syringes with subsequent analysis by gas chromatography using an electron capture detector (lower limit of detection: 0.1 ppm). In one operating room, a total of 28 surgical cases were sampled in which anesthetic gas flow rates ranging from 1 to 6 liters/minute were used. A recirculating air-conditioning system was employed in the rooms sampled. Halothane concentrations varied from 1.3 to 9 ppm when anesthetic gas flows were 1-2 liters/minute with 1.0% halothane being delivered; however, concentrations of 20-30 ppm were observed when the halothane delivery concentration was 1.0% and anesthetic gas flows were increased from 5 to 6 liters/minute. Concentrations of approximately 60 ppm were observed when 3% halothane was administered at a total gas flow of 5 liters/minute. Halothane concentrations in nearby laboratories and offices ranged from 0.4 to 6.2 ppm.

According to Strunin et al [142], halothane exposures occur during dental surgery. They determined the breathing zone halothane concentrations for both anesthetists and surgeons by collecting samples in clean, grease-free 20-ml syringes and analyzing by gas chromatography using a flame ionization detector (minimum detectable limits not given). Anesthetic gases were delivered by a nasal mask. Concentration measurements were made with the air-conditioning system off, with the air-conditioning system on (5 air changes/hour), with the air-conditioning system on and a small fan 3 meters from the nose mask expiratory valve blowing in the direction of the patient's face, and with the air-conditioning system on and waste gases vented to the floor from the expiratory valve. With the air-conditioning system off, mean halothane exposures for the anesthetist and dental surgeon were 23.1 and 68.3 ppm, respectively. Exposures were not significantly reduced when the air-conditioning system was on, 56.8 ppm for anesthetist and 73.8 for dental surgeon, nor when the local fan was employed, 46.3 ppm for anesthetist and 45.6 ppm for dental surgeon. When room ventilation was on and waste gases vented to the floor, mean concentrations of 25.2 and 18.5 ppm were determined for the anesthetist and surgeon, respectively. The authors concluded that while venting gases to the floor did reduce the oral surgeon's exposure, both the anesthetist and the oral surgeon were still exposed to a significant level of halothane.

Capon [143] measured concentrations of trichloroethylene in dental operations using trichloroethylene detector tubes (lower limit of detection: 10 ppm). All cases sampled used a gas flow of 8 liters/minute at a concentration of 1.5% trichloroethylene with no waste gas scavenging. Concentrations of approximately 25 ppm were found in the anesthetist's breathing zone when the patient's head was covered with a towel, and 50 ppm when the patient's head was not covered. An average concentration of 25 ppm was obtained during a simulated operating session using no general room ventilation.

Lane [144] checked halothane concentrations and distribution in an operating room with and without waste gas scavenging. Air samples were collected at the floor, breathing zone, and ceiling by filling 20-ml syringes and analyzed by gas chromatography using a flame ionization detector. Concentrations at the breathing zone level were 1 to 14 ppm without scavenging. Halothane concentrations at the ceiling ranged from 10 to 20 ppm and at floor level ranged from 5 to 10 ppm. Diverting waste gases to the floor did not significantly change overall concentrations. An injector scavenging system significantly reduced concentrations to approximately 1.0 ppm.

Lecky [145] conducted an analysis of air sample data from a number of operating rooms and dental operatories not using gas scavenging. These data were obtained from a consultant laboratory offering a central testing service for analysis of anesthetic trace gases. Samples were collected 30 minutes after the beginning of surgery by filling a leakproof aluminum container. Samples were sent to a central location and analyzed by gas chromatography (lower detectable limit not given). In the operating room, nitrous oxide concentrations ranged from 0 to 1,281 ppm (mean 177 ppm), enflurane from 0 to 234 ppm (mean 9.8 ppm), and halothane from 0 to 199 ppm (mean 11.7 ppm). In dental operatories, nitrous oxide ranged from 94 to 3,000 ppm (mean 793 ppm) and halothane from 1.5 to 36 ppm (mean 15.5 ppm). The author concluded that the higher concentrations in the dental operatories probably reflected both the exclusive use of nonrebreathing circuits in dental procedures and high anesthetic gas flow rates.

In 1974, Millard and Corbett [146] published their findings of exposure of dental personnel to nitrous oxide. During six different operative procedures using a nasal mask, breathing zone samples taken every 15 minutes with 600-ml gastight syringes were analyzed using gas chromatography with a helium ionization detector (no minimum detectable concentrations were given). The authors found that breathing zone nitrous oxide concentrations rose during the procedures. After 60 minutes of nitrous oxide administration, exposures for dentists averaged 6,767 ppm (SE ± 2,466 ppm) with exposures for the dental assistants averaging 5,867 ppm (SE ± 1,685 ppm).

Nicholson [147] reported measurements of halothane concentrations in four operating rooms, two recovery rooms, and adjoining halls and offices in two separate hospitals. Air samples were collected by filling 100-ml glass sampling bulbs using a syringe, and analyzed by gas chromatography using an electron capture detector (lower detectable limit: 0.001 ppm). Sixteen measurements were made in each area sampled. The operating room concentrations for the individual samples ranged from 0 to 1.59 ppm, with the highest average concentration being 0.38 ppm and the lowest average 0.03 ppm. Recovery room individual sample concentrations ranged from 0 to 0.62 ppm, with the highest average concentration at 0.09 ppm. Concentrations as high as 0.86 ppm were noted in the hallway of one hospital in addition to concentrations as high as 0.16 ppm in offices at that same hospital. This study lacks any specification regarding the types of anesthetic circuits employed, concentration and flow rates of anesthetic gases delivered, presence or absence of waste gas scavenging systems, and type of room air-conditioning used.

In another study, Nicholson et al [148] measured residual halothane concentrations in the same four operating rooms, two recovery rooms, adjoining halls and offices at two hospitals previously studied [147]. Room air samples were collected at 7 AM and 12 noon in each area for 12 days. Anesthesia was not being administered during any of the sampling. Air samples were collected by filling 100-ml glass sampling bulbs using a 50-ml syringe and then analyzed by gas chromatography using an electron capture detector. Duplicate analyses were performed on each sample and repeated if a variation greater than 5% was observed. Halothane concentrations increased in each area sampled between 7 AM and 12 noon. In the operating room, mean concentrations ranged from 0.003 ppm at 7 AM to 0.645 ppm at noon; in the recovery room, mean concentrations ranged from 0.007 ppm at 7 AM to 0.134 ppm at noon; and mean concentrations in adjoining halls and offices ranged from 0.003 ppm at 7 AM to 0.386 ppm at noon. Waste anesthetic gas control measures being utilized in the operating rooms sampled were not specified.

Mehta et al [149] reported the effect on halothane levels of commonly used anesthetic circuits, gas flows, clinical concentrations of halothane, and gas scavenging systems in the operating rooms and the expired air of operating room personnel. Three operating rooms were studied with two rooms having room air exchange rates of 10/hour and the third having no mechanical ventilation. Three anesthetic circuits were used. These were a semiclosed circuit with 7 liters/minute anesthetic gas flow (1.5-2% halothane), a respirator (mechanical ventilator) circuit with 7 liters/minute anesthetic gas flow (0.5% halothane), and a closed-circuit system with an anesthetic gas flow of 3 liters/minute (1.5-2% halothane).

Each patient was intubated with a cuffed endotracheal tube inflated to minimize anesthetic leakage. Air samples were taken during the middle of each operating session by filling 20-ml gastight syringes. Samples were taken approximately 5 feet above floor level at various distances from the patient's head and also at floor level. End tidal breath samples were also taken from anesthetists while they were administering anesthesia. All samples were analyzed by gas chromatography using a flame ionization detector.

The highest concentration of halothane (13.6 ppm) found by Mehta et al [149] was within a 2-foot radius of the patient's head and in the breathing zone of the anesthetist when a semiclosed circuit was used in a room without mechanical ventilation. These values were reduced by approximately 75% when room air exchange rates of 10/hour were used. With a closed anesthesia system, an overall average concentration of 3.3 ppm was observed with no room ventilation and 1.3 ppm with a room air exchange rate of 10/hour. With the mechanical respirator circuit, an overall average concentration of 2.7 ppm was observed without room ventilation and 0.2 ppm with room ventilation. These data also demonstrated uniform distribution of halothane throughout the operating room. Halothane in end expired air of the anesthetist followed closely the ambient halothane concentrations.

In two NIOSH Health Hazard Evaluation investigations, Levy [150,170] reported environmental surveys of operating rooms and recovery rooms in two hospitals that were not using waste gas scavenging. Samples were taken in the breathing zones of operating room personnel to evaluate exposures to halothane, nitrous oxide, and cyclopropane. Breathing zone halothane samples were collected using charcoal tubes with subsequent analysis by gas chromatography. Samples of nitrous oxide were collected by filling 30-liter sample bags and analyzed by infrared spectroscopy.

In the first hospital [150], nitrous oxide concentrations in the operating room ranged from 5 to 6,000 ppm with a median of 525 ppm. Halothane concentrations ranged from 0 to 21.3 ppm with an average of approximately 3.5 ppm. All recovery room halothane concentrations were below 0.1 ppm. In the second hospital, [170] nitrous oxide concentrations in cystoscopy rooms were 20 to 6,000 ppm with a median of 155 ppm, whereas general operating rooms concentrations ranged from 150 to 3,000 ppm with a median of 43.0 ppm. Halothane concentrations in the cystoscopy rooms ranged from 0.04 to 29.3 ppm with a median of 1.0 ppm and in the general operating rooms ranged from 0.3 to 7.0 ppm.

In 1975, Barton and Nunn [171] reported halothane levels in operating room air when totally closed anesthetic circuits were used to administer halothane at concentrations of 0.5-1.0%. Samples were collected in the 400-sq ft operating room, supplied with air-conditioning (20 air changes/hour), by filling 20-ml syringes for halothane analysis using gas chromatography (lower detectable limit: 0.01 ppm). Samples were collected prior to the start of anesthesia, when no halothane had been used during the previous 2 hours, and toward the end of the surgical procedure. A control concentration of 0.02 ppm was observed prior to the administration of halothane. At the end of the surgical procedure, halothane concentrations had risen only slightly, with the highest concentration observed being only 0.03 ppm.

Exposure levels and acceptable control procedures for dental procedures requiring inhalation anesthesia have been the subjects of research sponsored by NIOSH [172]. In a pediatric dental office without scavenging, Whitcher et al [172] noted that exposures of dentists averaged 1,100 ppm nitrous oxide (SD ± 330 ppm). In the oral surgeon's office, mean concentrations averaged 1,000 ppm (SD ± 630 ppm). These levels were determined by using a direct reading infrared absorption meter. The samples were time-weighted and collected during nitrous oxide administration.

A limited study, sponsored by NIOSH, was conducted by Whitcher and Hart at the Veterinary Medical Teaching Hospital, University of California at Davis, to determine the occupational exposure of veterinary personnel to inhalation anesthetics [written communication, December 1976]. Standard hospital anesthesia machines were used and breathing systems ranged from the Jackson-Reese modified T-tube for small animals to a standard circle absorber for medium-and large-size animals. The average breathing zone concentration of nitrous oxide, in the absence of control measures, was 310 ppm for two anesthetists during two different small animal surgical procedures. During surgery in a gelding, halothane concentrations in the anesthetist's breathing zone averaged 7.1 ppm. Measurements were obtained using an infrared gas analyzer.

The above studies, summarized in Table XIII-2, have shown significant exposure to all presently used inhalation anesthetic agents when waste anesthetic gas scavenging is not employed. While exposures were reduced when the operating theater was provided with high dilution rates by mechanical room ventilation, exposures still remained high.

(b) With Anesthetic Gas Scavenging

Several investigators have devised methods of scavenging waste anesthetic gases from anesthesia circuits and have made measurements of their control efficiency. The earliest report of scavenging efficiency was by Hirsch and Kappus [19] in 1929. The investigators used a crude scavenging system, consisting primarily of a vacuum cleaner and a large funnel. The decrease in ether levels in several operating rooms ranged from 34 to 72%. More recent measurements of waste gas exposures following adaptation for scavenging were reported by Whitcher et al [136]. When a scavenging popoff valve was attached to a wall suction system, halothane concentrations in the vicinity of the anesthesia machine (ie, anesthetist's exposures) averaged 0.79 ppm (SE $\pm$ 0.15 ppm). Using a scavenging nonrebreathing valve, concentrations averaged 0.73 ppm (SE $\pm$ 0.10 ppm). Sampling methods used by these authors have been described in subsection (a) of this chapter.

Nikki et al [137] reported the results of halothane and nitrous oxide measurements following adaptation of nonrebreathing and Ayre's T-piece systems for scavenging. Halothane concentrations averaged 0.85 ppm with a range of 0.01-1.9 ppm. Nitrous oxide concentrations ranged from 25 to 380 ppm with an average of 135 ppm. Pfaffli et al [138], using the same operating rooms studied by Nikki et al [137], reported similar concentrations following adaptation for scavenging.

Bruce [173] observed the efficiency of waste anesthetic gas scavenging using a scavenging popoff valve connected to the exhaust grille of a nonrecirculating air-conditioning system. Forty-five to 75 minutes after anesthesia induction, air samples, taken in the vicinity of the anesthesiologist by filling airtight syringes, were analyzed for nitrous oxide by gas chromatography (minimum detectable level: 20 ppm). Nitrous oxide was not detectable (<20 ppm) in 19 of the 25 air samples collected. Bruce reported an estimated average concentration of 24 ppm nitrous oxide.

In 1971, Corbett and Ball [134] reported the results of 10 determinations of methoxyflurane concentrations made during use of a gas trap over the anesthesia machine discharge valve. This trap consisted of a balloon fitted over the valve, with vapors shunted to the operating room's central suction system. With this device, room concentrations ranged from 0.015 to 0.095 ppm.

Usubiaga et al [141] determined scavenging control efficiency in their study of halothane exposures in the operating room. A rubber balloon was attached to the discharge valve (popoff valve) of the gas machine with waste gases from the balloon vented to wall suction (flow rates not given). With this rather simple system, exposures were generally reduced to below 1-2 ppm even when high gas flow rates (5 liters/minute) to administer 3% halothane were used.

Levels found in operating rooms using scavenging were reported by Lecky [145], though the scavenging methods were not specified. Nitrous oxide levels were 0-135 ppm with a mean of 35.5 ppm, enflurane ranged from 0 to 5.6 ppm with a mean of 0.90 ppm, and halothane ranged from 0 to 1.8 ppm with a mean of 0.24 ppm.

In a study of halothane concentrations in the operating room, Mehta et al [149] noted the efficiency of various waste gas scavenging techniques. The expired gases from a circle system and semiclosed system were vented through a scavenging gas relief valve and either released at the floor level or discharged outside the hospital through a metal pipe buried in the floor. The study demonstrated that releasing halothane at the floor level did not significantly reduce ambient concentrations. However, when waste gas scavenging was used in addition to a room air exchange rate of 10 changes/hour, overall halothane concentrations were reduced to below 0.2 ppm, irrespective of the type of anesthesia circuit, gas flows, and halothane concentration.

Kemi et al [174] used an empty operating room at Tokyo University to study the effects on halothane concentrations of nonrecirculating air-conditioning as the sole means of waste gas scavenging. The air-conditioning system was capable of 15 room air changes/hour. When the air-conditioner was on, halothane levels ranged from 0.19 to 0.93 ppm at the ceiling to 3.8 to 16.6 ppm 50 cm from the popoff valve. With the air-conditioning off, halothane levels ranged from 0.01 to 1.51 ppm at the ceiling to 3.68 to 50.20 ppm 50 cm from the popoff valve. When the air-conditioner was in use, no halothane was detected 3 hours after the vaporizer had been shut off. Without the air-conditioner, halothane was detected in the operating room 24 hours after the vaporizer had been shut off. This study demonstrated the value of good room ventilation in controlling the levels of waste anesthetic gases.

While the above studies generally demonstrated the feasibility of controlling waste anesthetic gases in the operating room to the levels prescribed in the recommended standard, none of them were performed with a complete waste anesthetic gas management program, including careful equipment maintenance, leak testing, and proper anesthetist work practices. Such a study was conducted by Whitcher et al [159]. Waste gas scavenging techniques and anesthetist work practices, as later presented in this chapter, were used with a semiclosed system with 5 liters/minute anesthetic gas flow. Measurements were made during steady state conditions (anesthesia in progress at least 30 minutes, patient not disconnected within preceding 15 minutes, and vaporizer not filled during immediate 15 minutes before sampling). Under these conditions, average anesthetic gas concentrations (at the air-conditioning exhaust grille) were kept below 1 ppm nitrous oxide and 0.025 ppm halothane.

In addition to determining minimum achievable levels, Whitcher et al [159] used a number of sampling techniques to determine both average room concentrations and personnel exposures under normal operating conditions employing scavenging. Average room concentrations (at the air-conditioning exhaust grille) of nitrous oxide were determined by collecting samples in gastight syringes throughout the workday with subsequent analysis by infrared spectroscopy. The mean concentration of nitrous oxide determined from 461 samples was 16 ppm (SE $\pm$ 1.8 ppm). These concentrations were found to be similar regardless of anesthetic technique (ie, face mask, endotracheal tube with or without ventilator) as illustrated in Table XIII-4. To more accurately determine average exposures, long-term samples were collected at the exhaust grille by filling gastight sample bags with a low flow air pump for several hours. Analysis for nitrous oxide was performed by infrared spectroscopy and halothane by gas chromatography with a flame ionization detector. Mean concentrations were 19 ppm (SE $\pm$ 3.0 ppm) for nitrous oxide and 0.24 ppm (SE $\pm$ 0.05 ppm) for halothane. Samples obtained in the proximity of operating personnel showed almost identical results, indicating uniform distribution of waste anesthetic gases in the operating room. Such a distribution is applicable when leaks are at a minimum. These data are summarized in Table XIII-5.

Control techniques for anesthetic procedures employing nasal masks, used primarily in the dental area, have been developed by Whitcher et al [172]. Using the control procedures recommended in this chapter (double mask, oral suction hook, and concentration equalizing fan), nitrous oxide exposures, determined by infrared spectroscopy, have been shown to average 14 ppm (SE $\pm$ 1.5 ppm) in the dentist's breathing zone. Average room concentrations were 13 ppm (SE $\pm$ 1.4 ppm).

Whitcher and Hart demonstrated the feasibility and effectiveness of control procedures in a veterinary hospital as part of a limited study sponsored by NIOSH [written communication, December 1976]. The control measures included the use of anesthesia machines which had been serviced to minimize leakage, and waste gas scavenging, which consisted of collecting the excess gases at the anesthetic breathing system and their disposal at the exhaust grilles of the nonrecirculating air-conditioning system. Average breathing zone concentrations for anesthetists were reduced to 7.8 ppm for nitrous oxide and 0.35 ppm for halothane.

A summary of the above studies on control by use of scavenging techniques is presented in Table XIII-3. These data demonstrate the feasibility of controlling concentrations to those prescribed in the recommended standard.

Summary of Presently Used Anesthetics and Inhalation Anesthetic Techniques

A Hospital Inhalation Anesthesia Practices Survey [175] was conducted by NIOSH to determine: (1) which anesthetic agents are presently being used and to what extent, (2) types of anesthesia administration techniques being used, and (3) methods presently in use to reduce waste anesthetic gas exposures to operating room personnel. Hospitals surveyed were chosen from the 1972 List of Health Care Institutions published by the American Hospital Association. Institutions were grouped according to five categories and are shown in Table XIII-7. To keep the number of hospitals surveyed manageable and to optimize the amount of information within the limits of available resources, only those institutions with 100 beds or more were surveyed. All hospitals in three of the categories with fewer than 500 institutions were surveyed. Randomly selected hospitals were surveyed from the two categories which included more than 500 institutions. Questionnaire response statistics are shown in Table XIII-8. There was a response rate of approximately 80%, which is considered excellent because of the complex nature of the questionnaire and the fact that response was strictly voluntary.

The survey results for the types of anesthetics used in hospitals in 1974 are given in Tables XIII-9 and 10. The most commonly used inhalation anesthetics were nitrous oxide, halothane, enflurane, cyclopropane, methoxyflurane, and diethyl ether. Approximately 5% of the hospitals surveyed used trichloroethylene in addition to limited use of chloroform and isoflurane (experimental).

The percentage of utilization of the five most common breathing circuits is presented in Table XIII-11. Table XIII-12 shows that the face mask and endotracheal inhalation are the most common methods of inhalation anesthesia administration (approximately 90%). The insufflation technique, which is difficult to control from a waste anesthetic gas exposure standpoint, was used in less than 2% of administrations.

The extent to which waste gas scavenging techniques were used in 1974 is summarized in Table XIII-13. Approximately 70% of the hospitals surveyed indicated that some form of waste anesthetic gas scavenging was being used. The efficiency of these scavenging techniques could not be ascertained from this survey.

Biologic Evaluation of Exposure

Corbett and Ball [134,176,177] reported breath decay curves for several anesthetics in anesthesiologists after routine occupational exposure and in patients following clinical anesthesia. Methoxyflurane was detectable in the end-expired air of patients for 10-18 days after anesthesia and for as long as 30 hours after exposure in anesthesiologists. Air samples collected in the area of the anesthesiologist contained 1.3-9.8 ppm methoxyflurane [134]. Halothane was detectable in end-expired air of patients 11-20 days after anesthesia. Halothane was detected in end-expired air of one anesthesiologist for 26 hours after a 70-minute exposure and for 64 hours following a 390-minute exposure. Halothane levels in the operating room air ranged from 1 to 10 ppm [176].

Levels of nitrous oxide present in the breathing zone of the anesthesiologist, while administering 60% nitrous oxide at 5 liters/minute, were reported by Corbett et al [177] to be 330-5,050 ppm. Nitrous oxide was detectable in end-expired air from 3 to 7 hours following routine occupational exposures ranging from 13 to 305 minutes. The limit of detection was 0.2 ppm. Halothane was detectable from 7 to 64 hours following occupational exposure of 20-390 minutes. Operating room levels of halothane ranged from 1 to 10 ppm.

Halothane concentrations in end-expired air of anesthetists were reported in 1969 by Linde and Bruce [131]. Following operating room exposures of 1-3 hours, the end-expired air of 24 anesthetists contained 0-12.2 ppm halothane (average 1.8 ppm). The overall average room concentration of halothane was 10 ppm.

Hallen et al [133] measured halothane concentrations in expired air and venous blood of operating room personnel. Expired-air samples were collected by having the subject fill a 5-liter plastic bag with a number of expirations and subsequent rebreathing six to eight times. Halothane concentrations were determined by gas chromatography. Venous blood samples were taken from exposed personnel at the end of a day's exposure with subsequent halothane analysis by gas chromatography. Halothane concentrations in the operating room at approximately the anesthetist's breathing zone ranged from 15 to 290 ppm with a mean of 67 ppm and a median of 29 ppm. Expired air concentrations ranged from a trace to 31 ppm with a mean of 5.2 ppm. Venous blood halothane concentrations ranged from 0.021 to 0.63 ppm with a mean of 0.16 ppm.

In 1971, Whitcher et al [136] reported end-tidal concentrations of halothane in breath samples of operating room personnel. Concentrations of halothane in end-tidal samples of 9 anesthetists (36 samples) and 27 operating room nurses (81 samples) were measured by mass spectrometry at intervals throughout the day. A control sample was obtained for each individual early in the morning before work in the operating room. During the workday, end-tidal halothane concentrations for nurses rose from 0.01 ppm to an average of 0.21 ppm while end-tidal halothane concentrations for anesthetists rose from 0.08 ppm to an average of 0.46 ppm. End-tidal concentrations greater than 1.0 ppm were found in six samples from the anesthetists and in samples from one nurse. Without scavenging, halothane concentrations in the operating rooms ranged from a mean of 8.69 ppm with nonrebreathing systems to 4.93 ppm with semiclosed circle systems.

Nikki et al [178] reported end-tidal and blood concentrations of halothane and nitrous oxide in surgical personnel before and after application of waste gas scavenging. End-tidal breath samples were collected in plastic bags before and after work with subsequent analysis by gas chromatography. Venous blood samples were also measured for halothane content by gas chromatography. In operating rooms without scavenging, mean expired air halothane concentrations rose from 0.13 at the beginning of the day to 1.28 ppm at the end of the workday. However, when gas scavenging was employed, mean concentrations rose from 0.05 to 0.12 ppm. Recovery room personnel also showed slight elevations of halothane concentrations in end-tidal air at the end of the workday. Nitrous oxide was only detected in a few of the samples from personnel working in unscavenged operating rooms (mean: 20.0 ppm).

In the same study [178], halothane concentrations in venous blood rose from a mean of 2.4 to 8.4 ppm in personnel working in operating rooms without scavenging. Personnel working in rooms with scavenging or in recovery rooms also demonstrated significant increases in venous blood halothane concentrations. The authors reported halothane concentrations in the air of operating rooms averaged 10.9 ppm without scavenging and 0.8 ppm with scavenging. Recovery room concentrations averaged 3.0 ppm [178]. Some expired air concentrations of personnel exposed to halothane are summarized in Table IV-1.

TABLE IV-1

HALOTHANE CONCENTRATIONS
IN EXPIRED AIR OF OPERATING ROOM PERSONNEL

Range of Anesthetic Exposure, ppm	Halothane in Expired Air, ppm
15 - 290	Trace - 31
4.9 - 8.7	0.21 - 1.0
0.8 - 10.9	0.12 - 1.3
0.6 - 12.9	0.8 - 12.2

Adapted from references 131,133,136,178