Evaluation and Control of Occupational Exposure to Anesthetic Vapors and Gases in the Quebec Hospital Environment

ÉTUDES ET RECHERCHES

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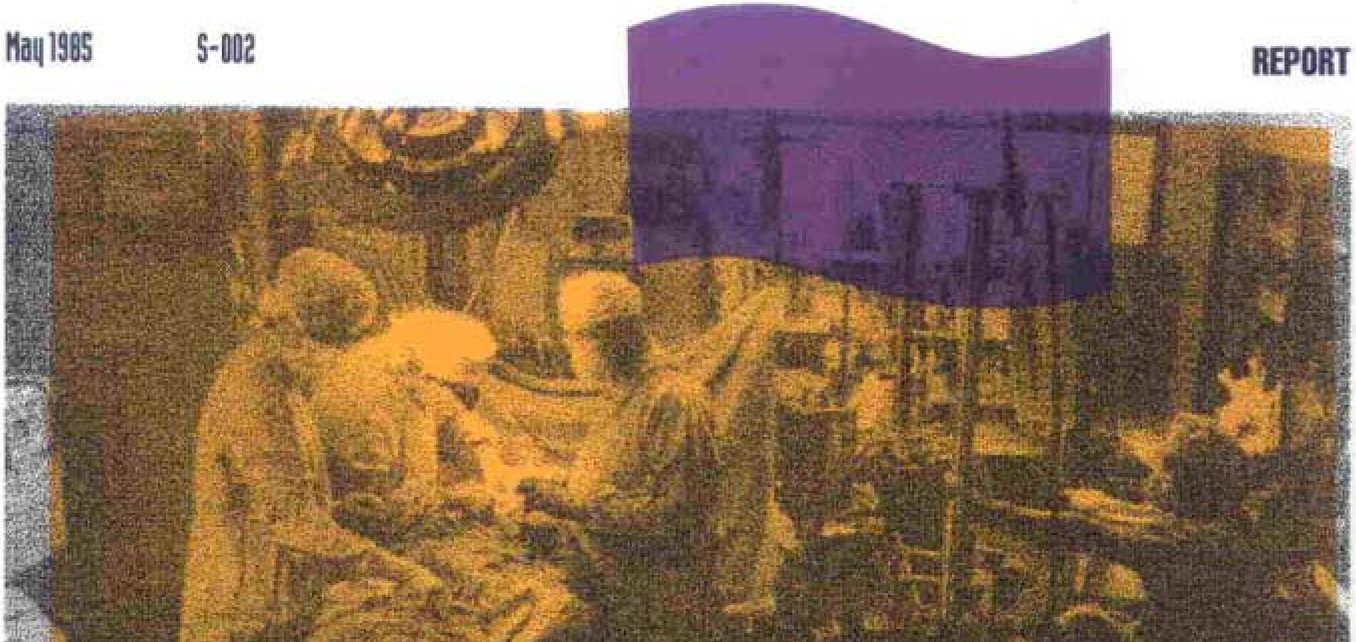
REPORT



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Preface

The aim of this report is to describe the problems associated with occupational exposure to anesthetic vapors and gases in the Quebec hospital environment.

This type of exposure has been reported many times by various authors and is regularly brought to the attention of the involved personnel and the media. The warning sent out by Alberta anesthetists and repeated by the press shows the preoccupation of the milieu.

At the request of community health departments, the laboratories of the Institut evaluated the exposure levels of personnel in three hospitals during surgery requiring general anesthesia. The collected data confirm present knowledge and give indications that the situation in Quebec is similar to that in other provinces, described elsewhere.

Considering that a thorough study more representative of the total milieu is inappropriate under the circumstances, those in charge of laboratory services decided instead to clearly identify the possible sources of contamination and to specify the different control measures. The Institut is in favor of the milieu taking charge while offering it the necessary tools, taking as an example the three hospitals studied.

Even though the data in this report are limited to the use of anesthetic vapors and gases in the hospital environment during surgical operations, the data could apply just as well to other nitrous oxide uses such as in dentistry and in cryogenics during cataract removal.

Introduction

Many surgical operations were and are made possible by anesthetic vapors and gases. The outcomes of these operations were and still are beneficial in the majority of cases. At present, the use of balanced anesthesia (gases, vapors, curarizing or morphinomimetic agents used conjointly) helps reduce the toxicity to the patient of each of the substances in the anesthetic mixture.

However, operating room personnel may be exposed to volatile anesthetic agents and to gases which are released by the equipment, the breathing circuits or due to poor work techniques.

Inhalation anesthesia leads to two types of exposure: that of the patient who has a single short-term high-level exposure, and that of operating room personnel, characterized by a lower but regular exposure, whose duration as well as intensity varies a great deal during a single day.

In spite of the discrepancy in epidemiological and toxicological data accumulated up to now or the difficulty in interpreting it, occupational exposure to residual anesthetic vapors and gases seems to present certain risks: several studies indicate that there would be a greater risk of spontaneous abortion in female personnel exposed to volatile anesthetics than in the general population. Other possible effects on health call for precautions to be taken (1, 2).

In Quebec, no standard governs the permitted maximum or average exposure to anesthetic vapors and gases. The data from epidemiological studies do not allow the setting of safe exposure standards. The only recommendation for an exposure threshold limit value in North America is that of the National Institute for Occupational Safety and Health (NIOSH) in the United States. In 1977 NIOSH recommended a time-weighted average of 25 ppm for nitrous oxide (3).

The evaluation of occupational exposure is the first step in the prevention of possible health effects. As a second step, the study of emission sources of anesthetic vapors and gases allows the introduction of appropriate control measures for reducing exposure. As a last step, the regular checking of the effectiveness of the control measures makes it possible to keep exposure at a low level.

The first aim of this report is to show the extent of the problem, using three industrial hygiene studies carried out inside typical hospitals. The second aim is to present simple and effective means for reducing personnel exposure to anesthetic vapors and gases. Finally, Appendix I presents a sampling strategy for anesthetic vapors and gases intended for those involved in occupational health and safety.

1. Exposed Population

The Quebec population exposed to anesthetic agents while they work is mostly made up of operating room personnel: anesthetists, nurses, surgeons, inhalation therapists, interns, and residents. In environments other than hospitals, dentists and their assistants, veterinarians and their assistants, and finally, the personnel involved in the industrial production of nitrous oxide and of halogenated agents may be exposed to anesthetic agents.

The lack of data concerning the exact number of exposed persons in Quebec as well as the concentrations to which they might have been exposed does not make it possible for us to know the situation in the past. In the United States, the National Institute for Occupational Safety and Health (NIOSH) in 1977 reviewed the literature relating to the environmental concentrations of anesthetic agents found in medical and dental environments (3).

NIOSH presented the results from approximately twenty studies carried out in various operating rooms between 1929 and 1977. The results are divided according to whether or not the room is equipped with a collecting system for gases and vapors. Nitrous oxide concentrations in the breathing zones in rooms not having this control measure vary from 0 to 9700 ppm with average concentrations between 3 and 6700 ppm. The rooms having control measures have average concentrations varying from 7 to 135 ppm with most of the averages being near 20 ppm. Concentrations of halogenated agents, especially halothane and enflurane, behave in the same way for the two types of operating rooms.

2. Anesthetic Agents

2.1 Substances Used

Inhalation anesthesia is carried out mainly using nitrous oxide (N_2O), which is administered at a rate varying from 3 to 4.5 L per minute with oxygen at a rate of 2 L per minute, producing concentrations in the order of 60 to 70%. Depending on the nature of the surgery, halogenated anesthetic vapors are added to the mixture in the order of 0.5 to 2.0%. The list of these anesthetic vapors is presented in Table 1 in descending order of consumption.

Table 1

Anesthetic Agents Used in Quebec

Generic Name	Commercial Name	Molecular Formula
Nitrous oxide	Nitrous oxide	N_2O
Halothane	Fluothane	CF_3-CHBrCl
Enflurane	Ethrane	CHClF-CF_2-O-CHF_2
Isoflurane	Forane	CF_3-CHCl-O-CHF_2
Methoxyflurane*	Penthrane	$CHCl_2$-CF_2O-CH_3

* This substance is hardly used since enflurane and more recently isoflurane, were introduced.

The agents most used are nitrous oxide, halothane, enflurane, and isoflurane. This study deals mainly with nitrous oxide concentrations. This gas is the best indicator of contamination in an operating room because of the high concentrations used.

2.2 Properties of Anesthetic Vapors and Gases

2.2.1 Nitrous oxide (4)

Nitrous oxide (N_2O), also known as dinitrogen monoxide, is a gas at ordinary temperature and pressure (15°C, 1 atm). It is colorless, practically odorless, and has a slightly sweetish taste. Very stable and rather inert chemically at room temperature, nitrous oxide is not flammable in air, but supports combustion. With heat (650°C, or 350°C in the presence of a catalyst), nitrous oxide decomposes irreversibly and exothermically into nitrogen and oxygen. Under these conditions, it can combine with combustible gases to make flammable or explosive mixtures.

Its solubility in the most varied solvents (water, organic solvents) is one of its most remarkable properties. In medicine and dentistry, it is considered to be a gas which is slightly anesthetic without significant toxic effect. Its anesthetic action appears when its concentration exceeds 70% by volume, whereas at lower concentrations it has a euphoric effect (laughing gas). Finally, it should be noted that at high concentrations in air, it acts as an asphyxiant by displacing oxygen.

2.2.2 Anesthetic Vapors (5)

Anesthetic vapors are mixed in concentrations in the order of 0.5 to 2% of the nitrous oxide and oxygen. Table 2 shows the principal substances used, as well as certain properties relevant to anesthesia.

Table 2

Selected Properties of Anesthetic Agents

Substance	Vapor pressure mm Hg (20°C)	Explosive limit in the presence of 70% N_2O and 30% O_2	Boiling point °C	Blood/gas partition coefficient	M.A.C. * vol. %
Nitrous oxide	—	nonflammable	−88	0.47	120
Halothane	243	4.8%	50	2.3	0.74
Enflurane	175	5.8%	56	1.9	1.68
Isoflurane	239.5	7.0%	48.5	1.43	1.15
Methoxyflurane	23	7.0%	104	12.0	0.20

* M.A.C.: minimum alveolar concentration of an anesthetic agent which stops all motor responses to surgical incisions in 50% of patients from 31 to 55 years of age.

3. Effects of Anesthetic Vapors and Gases on Health

3.1 Identifying Risks

The aim of this section being the effects of anesthetic gases on the health of operating room personnel, no mention will be made of the acute and subacute toxicity of these gases to the patient.

The previously mentioned NIOSH publication (3) is a reference document on anesthetic vapors and gases. However, two articles (1, 2), among the most recent on the subject, give an overview of the question of occupational risk related to anesthetic gases.

In order to be concise, the following summary is an account of the results presented in these two articles and must be interpreted with discernment.

3.1.1 Reproductive Effects

Many epidemiological studies have methodological weaknesses such as low rate of response, lack or poor definition of reference groups, and finally, not identifying the anesthetic agents involved nor their concentrations in the ambient air. In spite of the weaknesses, some of the studies indicate a higher risk of spontaneous abortion in female personnel exposed to volatile anesthetic agents. It would seem that nitrous oxide is the cause. Nevertheless, there is nothing which allows the possibility of anesthetic vapors having an effect on health to be ruled out.

Present studies on increased risk of congenital malformations with exposure to anesthetic agents do not establish so clear a connection.

3.1.2 Mutagenicity and Carcinogenicity

The results from mutagenic tests carried out on bacteria are few and contradictory. However, certain positive results as well as the evidence of mutagenic activity of the urine of anesthetists exposed to halothane are worth attention.

Up to now, studies carried out on animals have shown that chloroform, previously used as an anesthetic vapor, could cause renal tumors and hepatocellular sarcomas. On the other hand, studies carried out on animals with the other currently used anesthetic vapors do not allow one to conclude that they are carcinogenic.

Moreover, epidemiologic studies do not allow one to definitely conclude that anesthetic gases are carcinogenic. However, the authors of the mentioned articles, Edling (1) and Vainio (2), both recommend that these studies continue in order to confirm this effect on humans.

3.1.3 Effects on the Liver

In animals, high doses of halothane and methoxyflurane as well as chronic exposure to low concentrations of halothane, isoflurane and ethyl ether caused liver damage.

Several cases of liver damage were observed in patients and anesthetists exposed to halothane. Several large-scale epidemiological studies revealed an increased frequency of liver disease in anesthetists.

3.1.4 Effects on Kidneys

In animals, methoxyflurane and halothane affect the kidneys. The results of a study lead to the conclusion that chronic kidney impairment would be one of the causes of death in anesthetists.

However, methoxyflurane would only slightly and temporarily disrupt renal function in patients and personnel exposed to low concentrations. At high concentrations, methoxyflurane's renal toxicity is a potential cause of death.

3.1.5 Neurological Effects

Due to their lipid solubility, anesthetic agents are a neurotoxic risk. The few studies aiming to define the chronic neurotoxicity of anesthetic gases often led to contradictory conclusions.

Certainly there are isolated cases of voluntary abuse or high-level occupational exposure, but they are individual cases.

However, in spite of the lack of statistical or biological significance, all the experimental or epidemiological studies reveal tendencies which call for caution; from many physiological, neurological, or behavorial tests it would seem that the performance of exposed personnel is slightly lower than that of nonexposed personnel or of personnel exposed to lower concentrations, even though these concentrations are not always clearly specified.

3.1.6 Other Effects

Various studies suggest that prolonged exposure to nitrous oxide could impair vitamin B_{12} metabolism as well as produce tetrahydrofolate, which would explain the occurrence of myeloneuropathic syndrome in people having prolonged exposure to this agent.

Anesthetic agents depress the immune response. Present knowledge does not allow these observations to be expressed in terms of actual impact on health.

3.1.7 Conclusions

Certain epidemiological studies revealed a moderate increase in spontaneous abortions in female operating room personnel.

Concerning the other deleterious effects attributed to anesthetic agents, the actual data often produce contradictory conclusions or no conclusions at all.

However, in many respects the tendencies which become apparent are enough to suggest that precautions be taken by monitoring exposure to waste anesthetic agents and by monitoring the health of exposed personnel.

3.2 Exposure Criteria

Since there does not seem to be an obvious relationship between exposure to anesthetic agents and the effects on exposed personnel, the setting of safe exposure thresholds becomes difficult. In addition, the use of other anesthetic agents and the development of other anesthetic equipment over the last thirty years made certain epidemiological studies during this time more complicated.

3.2.1 Quebec

At the present time, there is no Quebec threshold limit value governing average or maximum exposure to the various anesthetic gases.

3.2.2 Ontario

Thresholds of 25 ppm* for nitrous oxide and 2 ppm for halothane, enflurane and isoflurane are recommended. At the present time, no standard is a law nor a regulation having force of law (6).

3.2.3 United States, National Institute for Occupational Safety and Health (NIOSH)

NIOSH was not able to determine exposure threshold limit values which could be considered "safe" during preparation of the publication *Criteria for Exposure to Waste Anesthetic Gases and Vapors* (3).

This organization recommended that risks connected to exposure could be minimized by reducing exposure to the lowest level possible. According to studies carried out in hospitals, this level was interpreted in the following way: When halogenated vapors are used alone, the exposure should be kept to the lowest level detectable by analytical methods appropriate to the workplace.

These exposure levels were specified in the following way:

a) Halogenated agents alone

halothane enflurane methoxyflurane fluroxene chloroform trichloroethylene	2 ppm**

b) Halogenated agents with nitrous oxide

halothane enflurane }	0.5 ppm**

c) Nitrous oxide alone or with halogenated agents

nitrous oxide	25 ppm

3.2.4 United States, American Conference of Governmental Industrial Hygienists (ACGIH)

Taking into account the effects on health observed during the use of halothane or enflurane in the hospital environment, and by comparing these effects to the toxicity of chloroform and trichloroethylene, ACGIH recommends the following exposure threshold limit values (7):

a) Halogenated agents alone

enflurane	75 ppm
halothane	50 ppm

b) Halogenated agents with nitrous oxide

enflurane halothane }	10 ppm	(in order to comply with the threshold for the mixture)

c) Nitrous oxide: No recommendation

3.2.5 Scandinavian Countries (8)

a) Denmark: Time-weighted averages of 5 ppm for halothane and 100 ppm for nitrous oxide are in effect.

b) Sweden: A time-weighted average of 5 ppm for halothane was adopted in 1979. A threshold of 100 ppm for nitrous oxide is recommended (1982).

c) Norway: Time-weighted averages of 5 ppm for halothane and 100 ppm for nitrous oxide are suggested (1982).

3.2.6 Discussion of Exposure Criteria

The contrast between the thresholds recommended by NIOSH and ACGIH for halogenated agents shows the differences in philosophy between the two organizations. The ACGIH recommendations for enflurane and halothane are based to a great extent on toxicological comparisons with other formerly used anesthetic agents, such as chloroform and trichloroethylene. This organization does not actually recommend any threshold for nitrous oxide, since this agent is presently being studied.

The only recommendation for nitrous oxide in North America is that of NIOSH, that of limiting exposure to 25 ppm. It is important to specify that this recommendation is based on studies in the hospital environment, aiming to define a minimum exposure level attainable using existing technology.

* ppm: parts of vapor or gas per million parts of contaminated air, by volume, at 25°C and 101.3 kPa.

** Based on a 45 L air sample, by adsorption on activated charcoal for a period not exceeding one hour

4. The System for Delivering and Administering Anesthetic Vapors and Gases

The systems used to deliver a mixture of anesthetic vapors and gases to the patient are made up of two distinct parts: the anesthesia machine and the anesthetic breathing circuits.

4.1 The Anesthesia Machine

The anesthesia machine is equipped with calibrated rotameters and precise vaporizers allowing the anesthetist to deliver known quantities and concentrations of oxygen and anesthetic gases and vapors to the anesthetic breathing circuit.

Figure 1 shows the operation of a typical machine and the additional connections necessary for delivering gases under high pressure, such as oxygen, nitrous oxide and air.

Vaporizers are used to vaporize halogenated anesthetic agents which are in liquid form. Each vaporizer is used for one specific halogenated agent since each agent has its own particular anesthetic properties.

Figure 1 shows a vacuum line located next to the other high-pressure connections. This line (if it exists) serves as a central exhaust for the evacuation system for waste anesthetic gases and vapors.

4.2 Anesthetic Breathing Circuits

The composition of the gas mixture inhaled by the patient can be adjusted by means of the breathing circuit between the patient and the anesthesia machine.

In general, several types of circuits are used in the hospital environment. The terms used to classify the various circuits are not standardized. For clarity we will be using Conway's classification (9) to describe the circuits currently in use in Quebec.

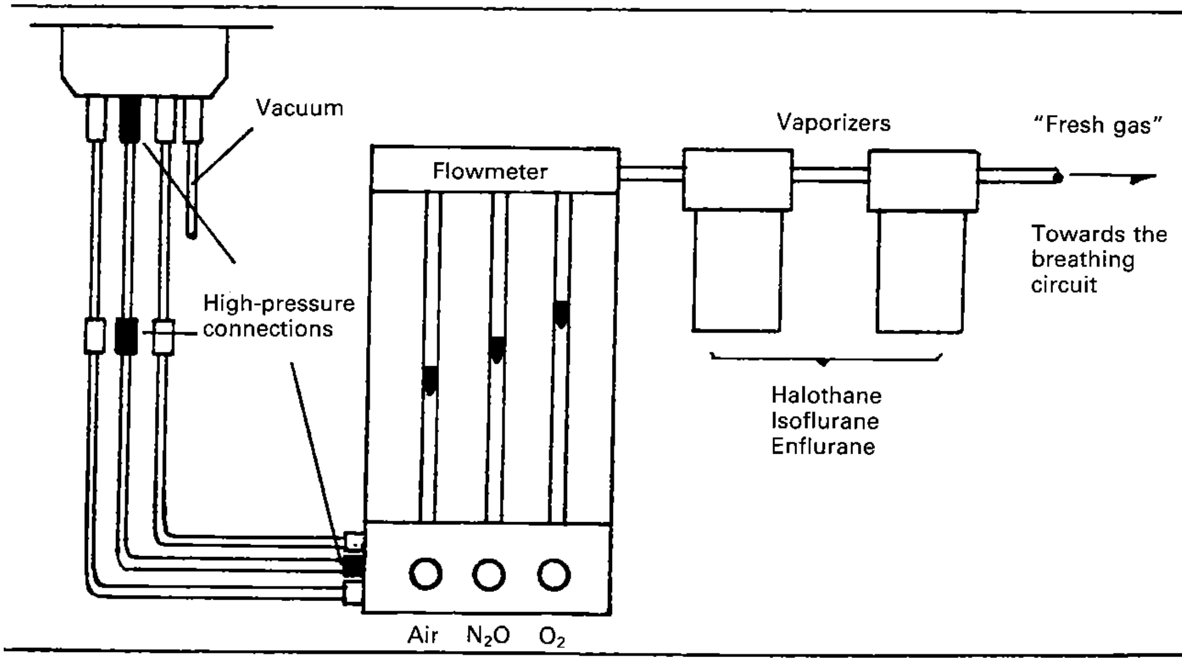
4.2.1 Open Circuit

The circuit is completely open to the atmosphere and there is a continuous supply of fresh gas. The simplest example of such a circuit is the administration of an anesthetic gas by means of a mask or a tube held several centimeters from the patient's face. The patient is always breathing fresh gas and room air. There is no recirculation of exhaled gases.

4.2.2 Semiclosed Circuit

Air from the atmosphere is prevented from entering. The amount of fresh gas delivered by the anesthesia machine is greater than that required by the system. Overflow gases are vented by the "pop-off valve".

Figure 1
The Anesthesia Machine



Semiclosed circuits are divided into two categories, with the second category being further subdivided.

a) Semiclosed circuit circle system with CO_2 absorption.

This circuit has the principal advantages of gas and vapor economy and of reducing the escape of these gases and vapors into the atmosphere (if the pop-off valve is connected to the collection system).

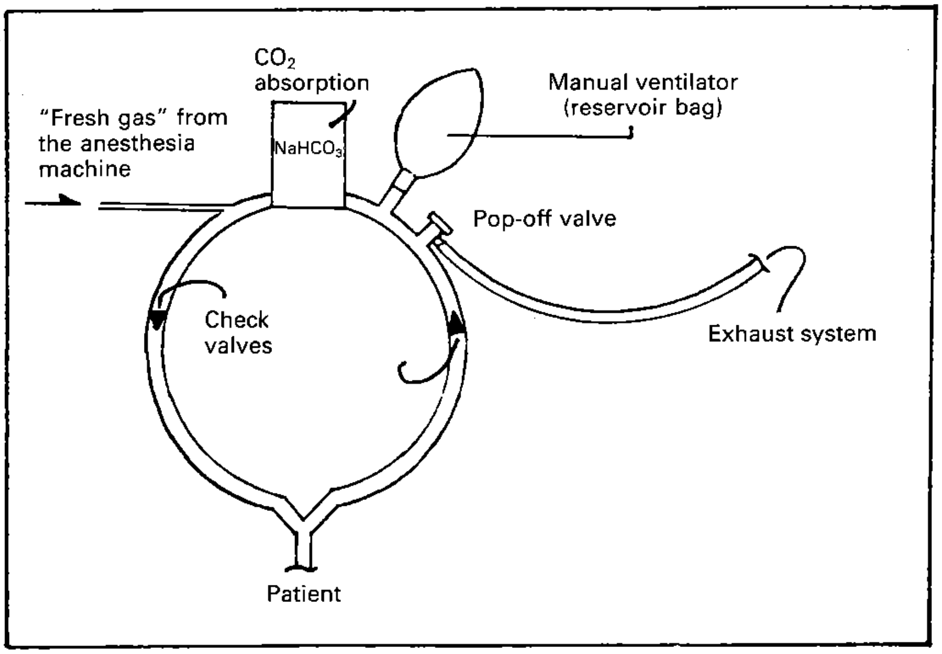
Figure 2 represents a semiclosed circuit circle system connected to a collection system.

The fresh gas mixture enters one side of the circuit and is carried to the patient. When exhaled, the gases return on the other side of the circuit, where part of the exhaled gas is recirculated by passing it through a CO_2 absorber. The part which is not recirculated is released by the pop-off valve and aspirated by the evacuation system.

When there is effective CO_2 absorption, the gas inhaled by the patient is free of traces of CO_2.

Figure 2

Semiclosed Circuit Circle System with CO_2 Absorption



b) Semiclosed circuit, without CO_2 absorption.

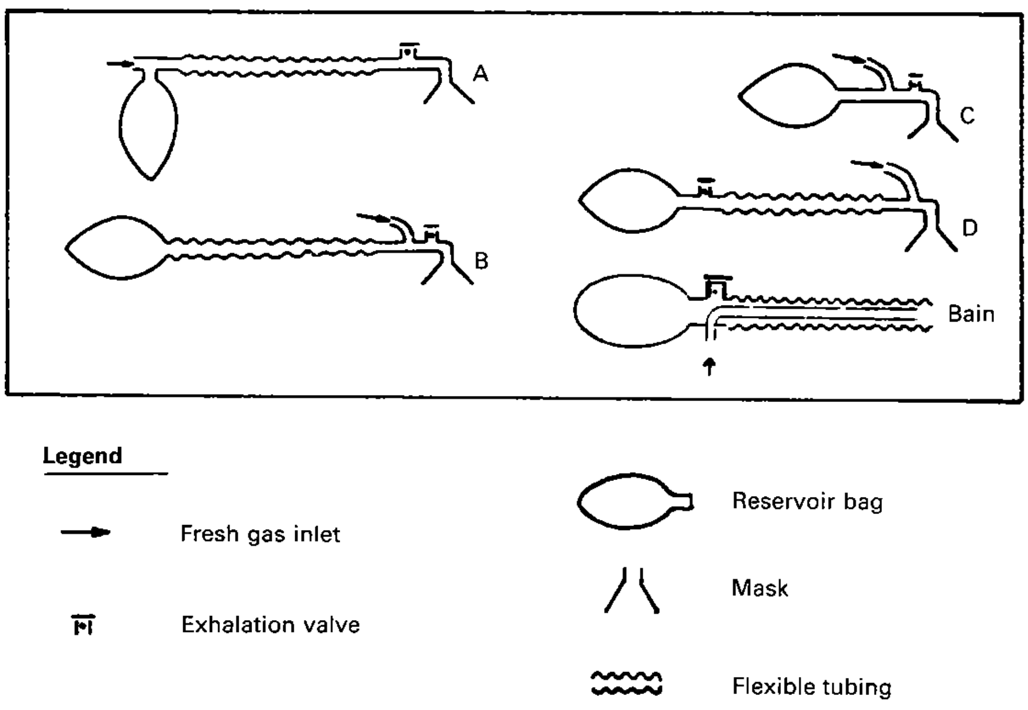
This type of circuit is divided into:
— Mapleson A, B, C, D
— Coaxial Bain circuit

In this type of circuit, there is no recirculation of gases exhaled through a CO_2 absorber. The percentage of exhaled gases that mix with fresh gases before being inhaled by the patient can be kept at a very low level by the anesthetist.

Figure 3 shows the Mapleson A, B, C, and D circuits as well as the Bain coaxial circuit. The circuits are similar but differ in the location of certain components common to the five circuits, namely, the fresh gas inlet, the reservoir bag and the exhalation valve. In addition, the circuits may differ in the length of the flexible tubing between the reservoir bag and the mask.

Figure 3

Semiclosed Circuits, without CO_2 absorption



c) The automatic ventilator

The automatic ventilator (also called the automatic respirator) is used to make the patient breathe during surgery. After the anesthetic induction period, the ventilator, an integral part of the anesthetic circuit, is connected in place of the reservoir bag. It is used when the duration of the operation demands it.

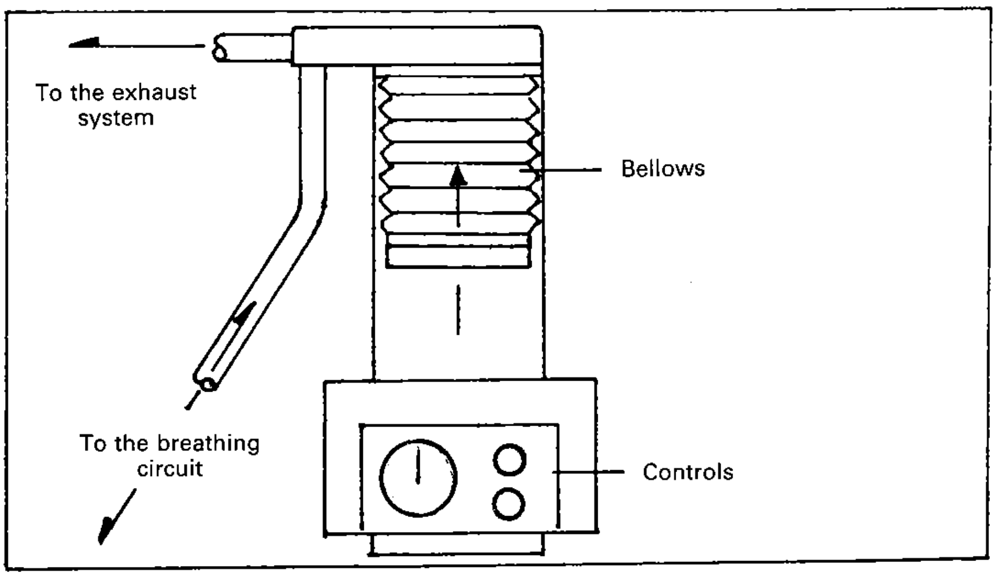
When the ventilator is connected to the circuit, the exhalation valve of the circuit is then closed. The overflow gases in the anesthetic circuit are vented by the automatic ventilator.

Figure 4 shows the operation of a typical automatic ventilator.

The excess gases and vapors in a breathing circuit are usually vented by the automatic ventilator when it is connected to the circuit. In the oldest models of ventilators, this excess of gas is vented into the room. The most recent models are equipped with collecting ports, which, once they are connected to the evacuation system, can ensure total collection of waste vapors and gases.

Most of the hospitals having old model ventilators have modified these machines so that waste vapors and gases can be collected by an evacuation system. The effectiveness of these modifications varies, not always ensuring proper control of emissions.

Figure 4
Automatic Ventilator (simplified)



5. Methodology

5.1 Hospitals Participating in the Study

The industrial hygiene studies summarized in this report were carried out in three hospitals in the Montreal region at the request of the three community health departments concerned.

The exposure problems connected to the use of anesthetic gases were evaluated in ten operating rooms during several surgical operations.

The studies were intentionally limited to those three hospitals, since the emission sources of anesthetic vapors and gases as well as the clearly demonstrated exposure tendencies are similar from one operating room to another.

5.2. Aims of the Sampling and Analysis

Sampling and analysis of gases and vapors were carried out in such a way as to determine:

— the concentrations in the breathing zone of operating room personnel;

— the emission sources and their contribution to personnel exposure.

Concentrations were thus measured at specific places corresponding to the breathing zones of the anesthetist, the surgeon and the nurses during the period of administration of gases and vapors to the patient.

The emission sources were characterized using a direct reading instrument which allowed continuous monitoring of concentrations near potential leaks such as the high-pressure line connections, the anesthetic circuits and the automatic ventilator.

Nitrous oxide served as the indicator of air contamination, since the ratio of this gas to the halogenated agent used at the same time is in the order of 25:1 to 50:1. In certain operating rooms where measurement was possible, we evaluated the concentrations of halogenated agents at the same time as that of nitrous oxide. These last results are incomplete and are not presented in this text.

5.3 Method of Measurement

Concentrations of nitrous oxide at the sources of emission and in the breathing zones of personnel are determined using a direct reading infrared instrument (10). This type of analyzer is equipped with a gas cell with mirror, into which the sample is continuously introduced using a pump with a high flowrate (8 L/min). The analysis of nitrous oxide using a wavelength of 4.5 μm makes it possible to measure concentrations from 0.5 to 600 ppm.

It is also possible to carry out instantaneous or integrated sampling by filling a sampling bag and taking it to a laboratory for nitrous oxide analysis.

A direct reading infrared analyzer (11-14) and/or integrated sampling by adsorption on activated charcoal with subsequent analysis in the laboratory can be used to measure anesthetic vapor concentrations. Passive dosimeters for sampling were not used, the precision and accuracy criteria not having been checked and validated.

When a halogenated agent and nitrous oxide are used together, interference is observed in the infrared analysis. Matrix calculations allowed the correct measurement of each of the constituents (15).

6. Results

The six following tables present the results obtained in each hospital. For each of the hospitals, two tables are given: the first shows the concentrations of nitrous oxide in the breathing zones of exposed personnel; the second table lists the components of the anesthetic system which leak nitrous oxide into the operating room air. A final table shows the concentrations of nitrous oxide in the air of the three recovery rooms of the three hospitals.

Notes on the Tables

a) Exposed personnel

In certain cases, it was not possible to distinguish between the exposure of two groups of people. This was due to the proximity of these people during certain operations. As a result, an exposure level representing the two groups is given.

b) Geometric mean

The geometric mean is used to express concentration results, these results being lognormally distributed. In the case of a single measurement, no range nor mean can be calculated. Therefore, the result is written in the "geometric mean or result (ppm)" column.

c) Evacuation system for gases and vapors

It should be noted that all the operating rooms were equipped with an evacuation system for anesthetic vapors and gases.

Table 3

Nitrous Oxide in the Air of Operating Rooms 1, 2, and 3 during Four Operations — Hospital A

Room	Operation and duration	Exposed personnel	Number of samples	Range of results (ppm)	Geometric mean or result (ppm)	Gas and vapor evacuation system
1	Vaginal hysterectomy 50 minutes	Anesthetist	2	100 to 145	120	Used
		Nurses Surgeon	5	32 to 84	55	
1	Vaginal tubal ligation 23 minutes	Nurses Surgeon	12	15 to 180	47	Used
2	Knee arthrotomy 45 minutes	Anesthetist	4	98 to 162	120	Used
		Nurses	2	340 to 410	373	
3	Tonsillectomy 38 minutes	Anesthetist	2	100 to 105	102	Used
		Nurses Surgeon	6	75 to 120	92	

Table 4

Characterization of Ethylene Oxide Emission Sources in Operating Rooms — Hospital A

Room	Operation and duration	Location	Number of samples	Range of results (ppm)	Geometric mean or result (ppm)	Remarks
1	Vaginal hysterectomy 50 minutes	On the anesthesia unit	4	175 to 238	203	
		Near connections: – 2nd connection located near the ceiling	3	260 to 500	357	
		– 3rd connection located behind the anesthesia unit	2	300 to 600	424	
		Behind the OHIO automatic ventilator	2	415 to 550	478	
2	Knee arthrotomy 45 minutes	On the BIRD MK II automatic ventilator	3	1527 to 2160	1760	Ventilator not connected to the evacuation system
		2nd connection	2	1500 to 2000	1720	High concentration due to the proximity of the ventilator
		3rd connection located behind the anesthesia unit	1	—	120	
3	Tonsillectomy 38 minutes	Center of room, before surgery	1	—	3.7	Evacuation system not connected
		2nd connection located ner near the ceiling	2	2140 to 3000	2530	Evacuation system connected for an operation
		Center of the room	1	—	13	9 minutes later
		Near the automatic ventilator	1	—	68	20 minutes after the start of surgery

Table 5

Nitrous Oxide in the Air of Operating Rooms 1, 2, 3 and 4 during Four Operations — Hospital B

Room	Operation and duration	Exposed personnel	Number of samples	Range of results (ppm)	Geometric mean or result (ppm)	Gas and vapor evacuation system
1	— 77 minutes	Anesthetist	3	291 to 330	310	Disconnected
		Anesthetist	10	80 to 130	96	Connected
		Surgeon Nurse	10	110 to 370	200	Disconnected
2	— 90 minutes	Anesthetist Surgeon Nurse	4	24 to 30	27	Used
3	— 220 minutes	Anesthetist Surgeon Nurse	8	770 to 880	850	Not used
4	— 70 minutes	Anesthetist	2	640 to 830	730	Not used
		Surgeon Nurses	5	330 to 460	430	

Table 6

Characterization of Nitrous Oxide Emission Sources in Operating Rooms — Hospital B

Room	Operation and duration	Location	Number of samples	Range of results (ppm)	Geometric mean or result (ppm)	Remarks
1	— 77 minutes	Near the OHIO automatic ventilator (evacuation system not connected)	2	320 — 387	352	
		Near the 2nd connection located near the ceiling (evacuation system not connected)	1	—	350	Contamination from the ventilator
		On the anesthesia unit (evacuation system not connected)	1	—	120	Same
2	— 90 minutes	Near the 2nd connection located near the ceiling (evacuation system not connected)	1	—	26	No major leak
		Behind the anesthesia unit	1	—	26	
3	— 220 minutes	At the outlet of the tube carrying the gases exhaled by the patient	1	—	10,000	
4	— 70 minutes	Near the 2nd connection located near the ceiling	1	—	940	

Table 7

Nitrous Oxide in the Air of Operating Rooms 1, 2, and 3 during Three Operations — Hospital C

Room	Operation and duration	Exposed personnel	Number of samples	Range of results (ppm)	Geometric mean or result (ppm)	Gas and vapor evacuation system
1	Laparoscopy 30 minutes	Surgeon Nurse	4	68 to 80	72	
		Anesthetist	1	—	82	Used
2	Removal of a tumor 60 minutes	Surgeon Nurse	5	92 to 165	126	
		Anesthetist — manual ventilation	6	16 to 30	23	Used
		— automatic ventilation	5	210 to 470	295	
3	Stapedectomy 90 minutes	Surgeon Nurse	8	360 to 520	442	
		Anesthetist	6	350 to 460	409	Not used

Table 8

Characterization of Nitrous Oxide Emission Sources in Operating Rooms — Hospital C

Room	Operation and duration	Location	Number of samples	Range of results (ppm)	Geometric mean or result (ppm)	Remarks
1	Laparoscopy 30 minutes	Near the anesthesia unit	2	94 to 140	115	
2	Removal of a tumor 60 minutes	Near the anesthesia unit	3	25 to 36	32	Manual ventilation of the patient
		Near the automatic respirator	1	—	2200	Automatic ventilation
		Behind anesthesia unit	2	1100 to 2600	1800	
3	Stapedectomy 90 minutes	Near the anesthesia unit	1	—	445	
		Near the automatic respirator	1	—	510	
		Near the 1st connection located near the ceiling	1	—	360	
		Near the 2nd connection	3	1200 to 2700	2000	
		Near the 3rd connection	1	—	700	

Table 9

Nitrous Oxide Concentrations Measured in Recovery Room Air — Hospitals A, B and C

Hospital	Number of samples	Range of results (ppm)	Geometric mean or result (ppm)
A	2	13 to 15	14
B	1	—	18
C	3	15 to 18	16.5

6.1 Interpretation of Operating Room Results

Operating rooms can be classified according to the extent of control of nitrous oxide exposure, by comparing the results obtained during sampling in the breathing zone to the value recommended by NIOSH (25 ppm). This extent of control is presented in the three following tables.

Table 10

Effective Control of N_2O Level (25 ppm ± 10%)

Hospital	Operating room	Exposed personnel	Concentration (ppm)
B	2	Anesthetist, surgeon, nurse	27
C	2	Anesthetist (during manual ventilation only)	23

In the first case, exposure control can be attributed to the absence of leaks from the connections, from the anesthesia unit, and from the automatic ventilator used, as well as attributed to the extent of continuous exhaust of waste gases.

In the case of operating room 2 in hospital C, the low exposure during the first part of surgery is entirely due to the use of the manual ventilator to make the patient breathe. It should be noted (Table 7) that when the automatic ventilator is used, the concentration is thirteen times greater. In Table 8, when this ventilator is not equipped with a vacuum port, the significance of the leaks is evident (2200 ppm).

Table 11

Average Control of N_2O Level (25 to 100 ppm)

Hospital	Operating room	Exposed personnel	Concentration (ppm)
A	1	Surgeon, nurse	47
C	1	Surgeon, nurse	72
		Anesthetist	82

Hospital A: In spite of the fact that the gas evacuation system is connected in operating room 1, the presence of low-pressure leaks from the connections and from the automatic ventilator keeps concentrations at rather high levels. The average exposures may seem rather low, but high concentrations were detected in the breathing zone of the anesthetist (100 to 145 ppm) as compared to the concentrations observed for the nurse and the surgeon (32 to 84 ppm).

Hospital C: During the operation in operating room 1, the concentrations varied little with time or sampling site, indicating the absence of punctual sources. The waste gas collection system was connected. The low concentrations can be attributed to manually controlled respiration.

Table 12

Inadequate Control of N_2O Level (100 ppm and higher)

Hospital	Operating room	Exposed personnel	Concentration (ppm)
A	2	Anesthetist	120
		Nurse	373
A	3	Anesthetist	102
		Surgeon, nurse	92
B	1	Anesthetist	96 to 310
		Surgeon, nurse	200
B	3	Anesthetist, surgeon, nurse	850
B	4	Anesthetist	730
		Surgeon, nurse	430
C	2	Surgeon, nurse	126
		Anesthetist	295
C	3	Surgeon, nurse	442
		Anesthetist	409

Hospital A: The high concentrations in operating room 2 come mainly from the automatic ventilator (1527 to 2160 ppm). The high concentrations near the 2nd connection reflect the proximity of the automatic ventilator in this room.

The results in operating room 3 show the possible contribution of a major leak (2140 to 3000 ppm) in a connection. This should be a rather rare occurrence because the noise caused by the leak could be heard.

Hospital B: The importance of using a scavenging system for gases exhaled by the patient is shown in the results from operating rooms 1 and 3. It was found upon arrival in operating room 1 that the system was not connected, giving results between 291 and 330 ppm. When the system was connected, concentrations were reduced to 80 — 130 ppm, a third of their previous values.

It was found upon arrival is operating room 3 that the gas evacuation system was not connected. The operation had been in progress for three hours. At the exhaust outlet of the tube containing the gases exhaled by the patient, concentrations above 10,000 ppm were observed.

It was impossible to check for leaks from the connections or from the automatic ventilator because any leak would have been masked by the high concentrations found in the air.

There was little variation in concentrations with respect to time or to the location of the sample collecting device, showing that equilibrium had been reached between the production of gases and their dilution by the general ventilation system of the room.

In operating room 4, the high concentrations come from two main sources: a leak from a connection and the overflow from the anesthesia circuit. The leak from the connection implies a variation in concentrations measured as a function of the location of the sample collecting device.

Hospital C: When the automatic ventilator was used in operating room 2, there was an immediate increase in concentrations due to leaks from the automatic ventilator. The odor of ethrane used with nitrous oxide was detectable near the anesthesia unit, possibly due to a leak from the vaporizer of the unit.

A leak from the connection on the nitrous oxide supply line in operating room 3 contributed to the contamination of the air in this room. In addition, the anesthetic gas evacuation system was not in use in this room.

6.2 Recovery Rooms

The concentrations found in the air of the three recovery rooms do not exceed any of the exposure criteria previously described.

6.3 Discussion of Results

6.3.1 Pollution and General Ventilation Systems

In spite of the fact that the operating rooms visited have rather high ventilation exchange rates (varying between ten and twenty air changes per hour), these general ventilation systems cannot ensure the reduction of gas and vapor concentrations in the breathing zones of personnel. In fact, other studies on air pollution in operating rooms conclude that the air flow of systems designed to minimize bacterial contamination during surgery is not adequate for reducing gas concentrations, which requires a complete mixing of operating room air (16, 17).

6.3.2 Evacuation Systems for Waste Vapors and Gases

In the operating rooms of hospitals B and C, the evacuation of overflow gases and vapors was carried out using vacuum ports originally planned for aspirating fluids during surgical operations. When these ports are needed in an operation, no gas scavenging can be done. In addition, the continual connecting and disconnecting of the anesthetic gas scavenger becomes a bother for personnel. Inevitably, the scavenging system remains permanently disconnected.

The operating rooms of hospital A were equipped with a central evacuation system specifically for anesthetic vapors and gases. The vacuum ports of the system were located near the other connections for nitrous oxide, oxygen and air. This central evacuation system was not used to its full capacity because there were other anesthetic circuits not connected to it. The pop-off valves and the ventilators of these circuits were not equipped with ports for the evacuation system.

6.3.3 Leaks and Other Punctual Sources

Table 5 shows how rapidly a single leak can contaminate the air in an operating room when there is no checking for, or control of, punctual sources of contamination. The concentration increases from 3.7 to 13 ppm in nine minutes.

Neither an evacuation system specifically for gases and vapors nor a general ventilation system can ensure the control of exposure when such leaks are present.

In the operating rooms visited, there were frequent high-pressure leaks in the gas supply lines as well as frequent low-pressure leaks in the anesthetic circuits.

According to the literature (18, 19), the other punctual sources of contamination are: the leaks during anesthetic induction, the filling of vaporizers, the checking of anesthetic equipment, starting gas flow before the mask is put on or before intubation, as well as the leaks from accidentally or intentionally disconnected tubing. During our evaluation, these emission sources certainly contributed to the high concentrations, but their individual contribution could not be checked. Elsewhere (18, 19), these punctual sources are considered as being very frequent and as significant as the high- and low-pressure leaks previously described. The presence of these sources depends to a great extent on work practices and techniques during preparation, maintenance and obviously during use of the anesthetic equipment.

6.3.4 Exposure of Personnel

The evaluation carried out during the administration of anesthetic vapors and gases shows that exposure of operating room personnel to nitrous oxide in the three hospitals visited varies from 26 to 850 ppm.

The level of exposure is the result of factors such as:

— the number of operations and their duration;
— whether or not a waste gas scavenging system is used;
— low-pressure and high-pressure leaks;
— the types of anesthesia machines or ventilators used;
— the work methods and practices.

The concentration can be from two to thirty times higher in one operating room than in another inside the same hospital. These differences are the result of the previously listed factors.

6.3.5 Reducing Exposure

The variations in concentration from one operating room to another show that efforts are presently being made to reduce personnel exposure. With the elimination of high-pressure leaks, exposures in the order of 50 to 100 ppm are found, compared with 600 to 800 ppm when these leaks are present. Additional efforts by means of an emission control program would allow exposure to be reduced to concentrations in the order of 25 ppm, the value recommended by NIOSH. Moreover, nitrous oxide concentrations found in operating room 2 of hospital B clearly show this.

7. Recommendations

Reduction of exposure to anesthetic vapors and gases must be carried out by means of a complete emission control program, which includes:

— the use of an appropriate collection and evacuation system for waste vapors and gases;
— the implementation of a program of routine inspection of the anesthetic equipment in order to minimize leaks;
— the evaluation of the work practices and techniques of personnel in order to minimize leaks.

7.1 Collection and Evacuation Systems for Waste Vapors and Gases

A collection and evacuation system specifically for waste vapors and gases should be installed in the operating rooms lacking them. The systems using vacuum ports installed for surgical use can be effective on condition that these ports be reserved for anesthetic gases.

The installation of a central system having ports located near the gas- and air-supply outlets facilitates and encourages its use.

Safety valves on circle anesthesia circuits must be compatible with the collection system. In addition, the regulators must be airtight.

New ventilators are usually adapted for installation on existing collection systems. Old model ventilators can be adapted to collect overflow gases (3, 20).

It is important to ensure that the collected vapors and gases be exhausted in such a way as to prevent any recontamination of the workplace. The overflow must not be vented into the return air vent of an air recirculation system.

7.2 Checking of Anesthesia Equipment

Detailed methods for checking equipment for low-pressure and high-pressure leaks are described by NIOSH (3). The gas supply, the high-pressure lines, and the connections to outside the operating room should be checked once a year, according to the Bureau de normalisation du Québec (21).

The methods described by NIOSH for checking the breathing circuit for low-pressure leaks can be carried out without using any other apparatus than the anesthesia machine. Checking for leaks can be painstaking because of the high number of potential emission sites. The best method for rapid detection and correction of high-pressure leaks is to use a direct reading infrared analyzer. The principle of the method is the following: In an operating room where no surgery is in progress, a high-pressure leak equilibrates with the operating room air at an expected concentration; thus, nitrous oxide concentrations above 5 ppm show that there is one or more excessive leaks which can be located using the same instrument (3).

One factor to be considered is the cost of such an instrument, $6,000. On the other hand, the instrument saves time when compared to other methods for checking (e.g. Snoop® solution) which run the risk of not properly locating the leaks or not detecting them rapidly enough. The proper use of a direct reading instrument makes it possible to prevent exposure.

7.2.1 Automatic Ventilator

At present, there is no simple and quick method to check for leaks from ventilators (3). The care taken during disassembly and reassembly for cleaning will to a great extent determine whether there are leaks.

7.2.2 Frequency of Checks

NIOSH (3) recommends that one should check for high-pressure leaks four times a year. Checking for low-pressure leaks from the breathing circuit should be done more often (once a day according to NIOSH) or before each use. The frequency of checks obviously depends on how much the machines are used and on the number of people who use them. Each hospital is capable of determining how much they are used and also the minimum checking frequency necessary to prevent leaks.

7.3 Work Practices and Techniques

Work practices and techniques should be examined and evaluated in order to minimize the punctual sources of contamination.

In particular:

— The collecting and evacuation system should be connected and checked before anesthetic vapors and gases are administered.
— Vaporizers should be filled in a ventilated place and preferably in a room which will not be used soon afterwards. Vaporizers should be shut off when not in use.
— Turning on gas flow before the start of administration of the anesthetic must be avoided.
— The reservoir bag should be exhausted into the scavenging system after it is disconnected from the anesthetic system.

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Conclusion

Regularly occurring vapor and gas leaks in most of the evaluated operating rooms expose operating room personnel to concentrations often significantly higher than the threshold recommended by NIOSH. The extent of exposure confirms the results of similar studies carried out in other provinces, in the United States and in Europe. This suggests a similar situation in the whole hospital system in Quebec.

Certain aspects of the toxicity of nitrous oxide and of halogenated agents require clarification. Nevertheless, the actual data suggest that precautions be taken when these substances are used.

Adequate collecting systems and regular checks for leaks can contribute to keeping exposure to levels at or below 25 ppm. To arrive at this result, personnel must be informed about the concentrations to which they may be exposed, they must be sensitized to the health risks, and finally, they must be trained in the use of all available control measures.

Appendix I. Sampling Strategy

Since the aim of an industrial hygiene study is to evaluate and control exposure, the series of steps in this type of operating room study can be summarized as:

— detection of high-pressure leaks;
— detection of low-pressure leaks.

The strategy is presented in Table 13. The evaluation of exposure sources and of the twelve anesthesia unit check sites are presented in chronological order.

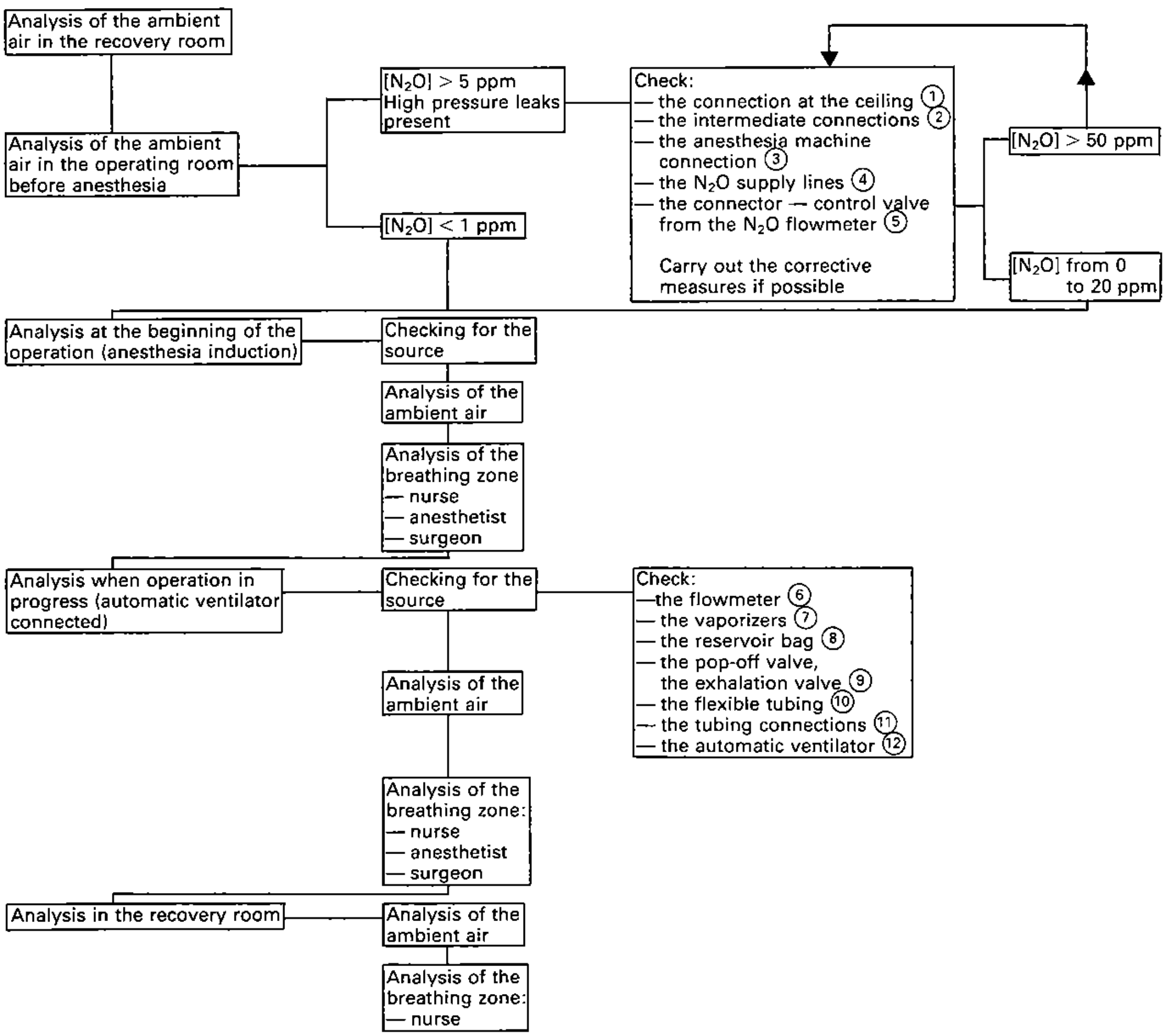


Table 13: Sampling Strategy

I.1 Checking for High-Pressure Leaks

There are many possible locations for high-pressure leaks, and their detection can be painstaking when using traditional methods (Snoop® solution). The easiest and fastest method is to use a direct reading analyzer. This method is based on the principle that in an operating room where no operation is in progress, a high-pressure leak will come to equilibrium with the operating room air at an expected concentration. Therefore, concentrations of nitrous oxide higher than 5 ppm in the air indicate the presence of one or more excessive leaks which can then be located using the same instrument (3). In the same way, concentrations in the air below 1 ppm show the absence of high-pressure leaks.

The detection of high-pressure leaks is carried out under the following conditions:

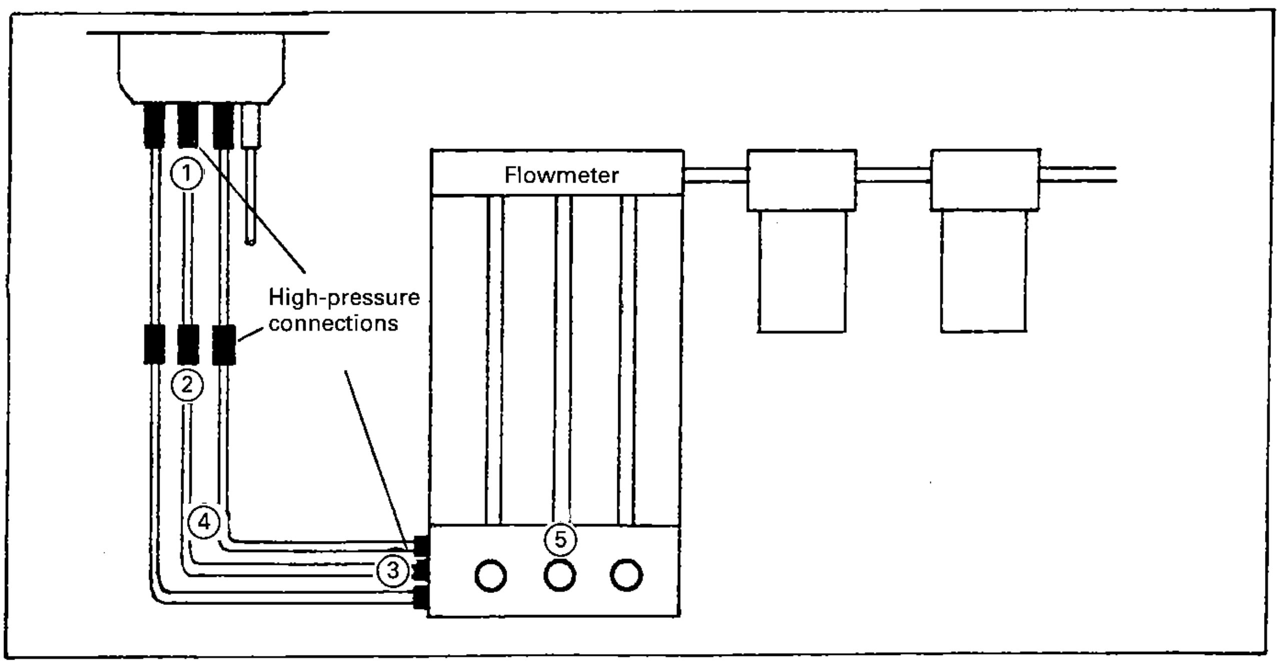
— the anesthesia machines should not be used for at least an hour before checking for leaks;
— the operating room doors must remain closed before and during checking for leaks.

The components of the high-pressure nitrous oxide supply system which are susceptible to leaks are:

1- the connection at the ceiling;
2- the intermediate connections;
3- the anesthesia machine connection;
4- the N_2O supply lines;
5- the connector and the gas-lines of the anesthesia machine beginning at the N_2O connection and ending at the control valves of the flowmeters.

These potential leak sites are shown in Figure 5.

Figure 5
High-Pressure Leaks



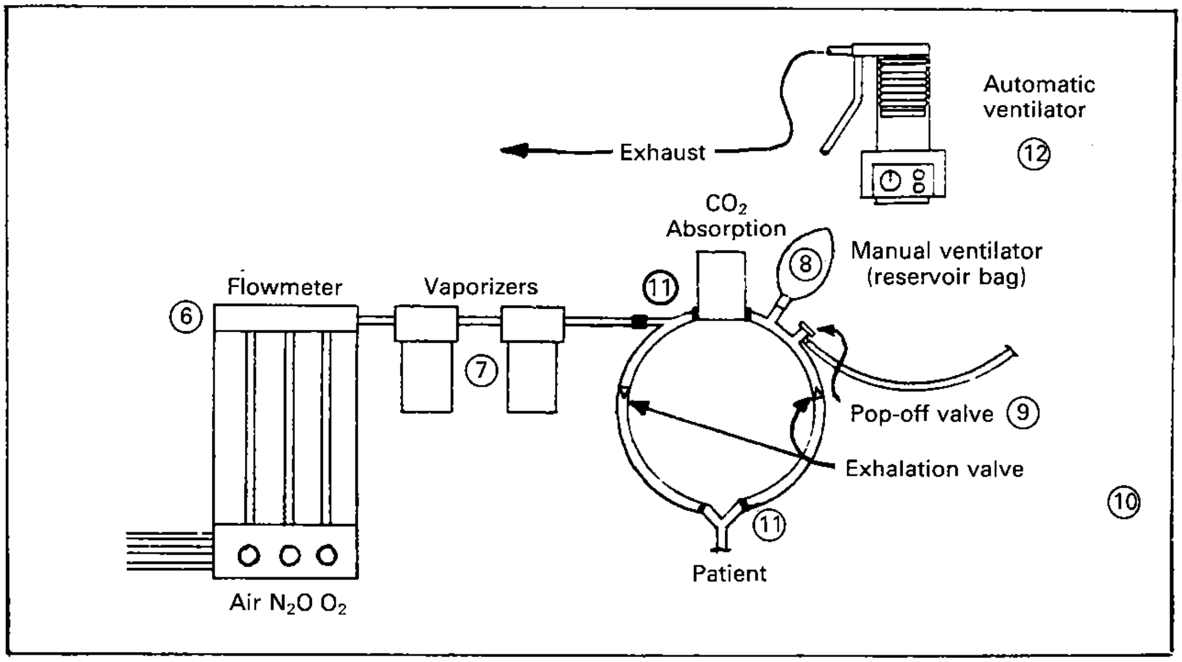
I.2 Checking for Low-Pressure Leaks

Low-pressure leaks show up in the anesthesia machine starting at the flowmeter, and in the breathing circuit ending at the patient. The places liable to produce leaks are listed below:

6- flowmeter;
7- vaporizers;
8- reservoir bag;
9- pop-off valve, exhalation valve;
10- flexible tubing;
11- tubing connections;
12- automatic ventilator.

Figure 6 presents, as an example, a circle breathing circuit with CO_2 absorption, showing the sites of possible leaks.

Figure 6
Low-Pressure Leaks



At the beginning of the operation, during anesthesia induction, the patient is on manual ventilation. At this time, samples are taken in the breathing zones of the anesthetist, the surgeon, and the nurses.

Subsequently, the ventilator is connected to the anesthesia circuit and to the evacuation system. Analyses using IR are carried out around the automatic ventilator and at check sites 6 to 11. After evaluating the emission sources, the concentrations are measured in the breathing zones of personnel in order to evaluate the contribution of these leaks.

I.3 Protocol for Evaluating Low-Pressure Leaks in a Breathing Circuit Having CO_2 Absorption. Method for Measuring the Leak Rate

Low-pressure leaks can be detected by using a method that measures the leak rate in the breathing circuit. A rate higher than 1.0 L/min shows the presence of major leaks in a component of the circuit. As a rule, the rate should not exceed 100 mL/min. This technique does not require a direct reading analyzer, but uses only the manometer on the anesthesia machine.

The method is the following:

a) Prepare the anesthesia machine and the breathing circuit in the way that it is usually used during anesthesia;
b) Occlude the breathing circuit at the gas outlet;
c) Increase the pressure in the system to 30 cm H_2O, as read on the manometer of the CO_2 absorber. This can be done using oxygen;
d) Add enough oxygen through the flowmeter to maintain a pressure of 30 cm H_2O in the circuit. The amount of oxygen necessary to maintain pressure is an indication of the leak rate.

This check can be shortened using a constant flow of oxygen of 100 mL/min. If the pressure in the system increases, the leak rate is acceptable.

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