CONTROL OF OCCUPATIONAL EXPOSURE TO N_2O IN THE DENTAL OPERATORY

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ABSTRACT

The use of N_2O as an inhalation sedative-analgesic in dentistry is a widely accepted practice. This procedure is associated with occupational exposure to trace amounts of N_2O as well as to other inhalation agents employed, a phenomenon recently suggested as being hazardous to the health of dental personnel. Reported health hazards associated with the use of such agents include a 78 percent increase in the spontaneous miscarriage rate of the wives of male dentists and a 156 percent increase in the incidence of liver disease in the dentists themselves. A possible, but yet unproven, cause of these health hazards is low grade chronic anesthetic exposure. This possibility indicates the prudence of holding occupational exposure to the inhalation anesthetics to the lowest reasonably achievable level. To this end, several control measures have been developed which includes:

1. Use of a specially designed scavenging mask.
2. Venting the patient suction machine to a safe disposal site outside the building.
3. Minimizing speech by the patient during dental procedures.
4. Regular preventive maintenance procedures for anesthetic equipment.
5. Frequent leak testing of the anesthetic equipment by in-house personnel.
6. Use of an air sweep fan when necessary to dilute the concentrations of anesthetic inhaled by personnel.
7. Monitoring N_2O in the breathing zone of the dentist.

The above measures are designed to be: easily performed by the dentist; compatible with safe practices in dental inhalation analgesia and anesthesia; effective in reducing gas concentrations inhaled by personnel.

Without the above control measures, the concentration of N_2O measured in the dentists' breathing zone averaged 900 ± 55 ppm ($\pm$ S.E.). Use of the above measures was effective in reducing the dentists' inhaled mean concentration to 14 ± 1.5 ppm, representing a -98 percent reduction. These data were obtained during the conduct of 157 dental procedures completed in the operatories of four general dentists, two oral surgeons and two pedodontists. In an additional series of 47 anesthetic procedures studied in an oral surgical suite with two companion operatories where control measures were applied, the dentists' mean inhaled concentration of N_2O was 31 ± 4.8 ppm. On the basis of these studies, a concentration as high as approximately 50 ppm N_2O measured under the specified circumstances is presented as reasonably achievable during routine dental anesthesia/analgesia.

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Mr. Glenn E. Brown is credited with development of the scavenging mask. The statistical analysis shown in Appendix A was developed by Dr. Byron W. Brown.

The technical assistance of Mrs. Jeanne Daney, Miss Ann C. Zimmerman, and Messers Douglas and Bruce Whitcher is acknowledged.

Gas analyzers were donated by Air Products and Chemicals; Cavitron Corporation; Ohio Medical Products; Sensors Incorporated; and Wilks. Summitt Services donated production versions of the newly developed scavenging nasal mask. Littell's Oxygen, Incorporated, provided samples of their masks. Gas scavenging and air monitoring equipment were provided by Boehringer Laboratories, Incorporated.

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I. INTRODUCTION

During administration of inhalation analgesia and anesthesia in operative dentistry, anesthetic* agents such as N_2O and halothane unavoidably leak into the room air where they may be inhaled by all personnel. This is a suspected cause of health hazards which have been identified in epidemiological survey studies of the health of dentists and operating room personnel. Laboratory evidence obtained in animals is supportive. Although it is not proven that these health hazards are caused by occupational exposure to the anesthetics, the combined weight of the epidemiological and laboratory evidence has been an important factor in the decision of ad hoc committees appointed by the American Dental Association and the American Society of Anesthesiologists to recommend the universal application of control measures.

At the present time, it is impossible to describe any single inhalation anesthetic agent or combination of agents as more toxic than another. None of the epidemiological studies completed to date have made any attempt to separate population groups according to exposure to specific agents, and anesthetics are frequently administered in combinations. Although precise data do not exist, N_2O by itself must also be considered potentially toxic under conditions of chronic exposure. Until further data are available, it would seem prudent to maintain the lowest, reasonably achievable concentrations of all inhalation anesthetics. In the hospital, this has been cited as less than 30 ppm for N_2O.[1] The present studies suggest that a concentration as high as approximately 50 ppm N_2O is reasonably achievable in the dental operatory.

The control measures to be recommended in this report were developed with a view towards achieving a maximum reduction of concentrations of anesthetic inhaled by the dentist while imposing a minimum of inconvenience and without modification of familiar, safe anesthetic practices.

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*In this text, the term "anesthetic" applies to N_2O, halothane, and other vapors which may be administered to the patient for anesthesia or analgesia.

II. POTENTIAL TOXICITY OF INHALATION ANESTHETICS

A. Epidemiological Surveys

In a previously reported survey of the health of dentists[2] (Table 1), the professionals were separated into a group, including dentists who employed

Table 1

SPONTANEOUS ABORTION RATES PER 100 PREGNANCIES
IN SPOUSES OF DENTISTS
AND
LIVER DISEASE RATE PER 100 DENTISTS

	Exposed Dentists		Unexposed Dentists		
	Sample Size	Standardized Rate ± S.E.	Sample Size	Standardized Rate ± S.E.	p
Spontaneous abortion	887	16.0 ± 1.8	1541	9.0 ± 1.0	<0.01
Liver disease	1528	5.9 ± 0.4	1249	2.3 ± 0.4	<0.01

From Cohen, et al., JADA 90:1291-1296 (June) 1975.

inhalation anesthetics more than 3 hours per week, and were compared with a control group which used no inhalation anesthetics in their practice. In the exposed group, liver disease was reported in 5.9 ± 0.4 (± S.E.) percent of dentists, in comparison with 2.3 ± 0.4 percent in the control group. Spontaneous miscarriage was reported in 16 ± 1.8 percent of pregnancies of the wives of dentists who employed inhalation anesthetics, in comparison with 9.0 ± 1.0 percent for the unexposed controls. These data are statistically significant ($p = < 0.01$).

A strong point in the above study is the similarity of the control group: dentists are compared to dentists, the main difference being that one group used inhalation anesthetics, while the other did not. Limitations include the relatively small proportion of the total membership of the ADA sampled, and the absence of identification of the specific anesthetic agents administered. This latter limitation is attenuated by statistical analysis of excess morbidity which could be attributed to the potent agents. It is concluded that the halogenated anesthetics alone do not explain the positive findings of the survey and that N_2O exposure must be an important contributing factor, if not the principal factor (see Appendix A).

Additional epidemiological survey studies completed in this country and abroad further suggest similar dysfunction associated with work in the operating room, presumably with exposure to the inhalation anesthetics. The most comprehensive of these studies includes data obtained from 40,044 respondents. This study was jointly conducted by the National Institute for Occupational Safety and Health of the Department of Health, Education, and Welfare and the Ad Hoc Committee on Effects of Trace Anesthetics on the Health of Operating Room Personnel of the American Society of Anesthesiologists.[3] Selected positive findings are shown in Figure 1. In this study, females working in the operating room demonstrated an increased incidence of spontaneous abortion and carcinoma. Birth defects in their offspring were also increased, as well as in the offspring of the nonoccupationally-exposed wives of exposed male anesthetists. In both sexes, liver disease (serum hepatatis excluded) was increased. Increased incidence of spontaneous miscarriage and birth defects are confirmed in a survey of the health of female anesthetists in the United Kingdom.[4,5]

B. Laboratory Evidence

A relationship of these health hazards to chronic exposure to inhalation anesthetics is also suggested by laboratory studies. Such evidence includes teratogenic effects in various species upon exposure to a wide group of inhalation agents at anesthetic concentrations;[6] decreased survival rate in various species upon exposure to inhalation agents present in trace concentrations;[7] ultrastructural changes in the central nervous system of rat fetuses following a single maternal exposure;[8] and decreased ability to solve maze problems in rats exposed to low concentrations of halothane.[9] Rats also show evidence of testicular damage after a minimum of 2 days' exposure to 20 percent N_2O.[10]

Experimental studies in man designed to test cognitive and motor skills show that exposure to trace concentrations of anesthetic gas mixtures, N_2O/halothane or N_2O/enflurane, and also N_2O by itself, results in a decreased ability to perform complex tasks.[11,12] These studies suggest the possibility that the performance of exposed dentists might be somewhat below peak efficiency.

C. Other Relevant Literature

Not all investigators are convinced that the health hazards in anesthetizing locations are most likely related to anesthetic exposure. Fink and Cullen[13] suggest that stress may play an important role.

Smith and Shirley[14] unsuccessfully attempted to confirm the results of Bruce's studies[11,12] of cognitive and motor skills. The differences in techniques employed in these studies may explain the difference in results.

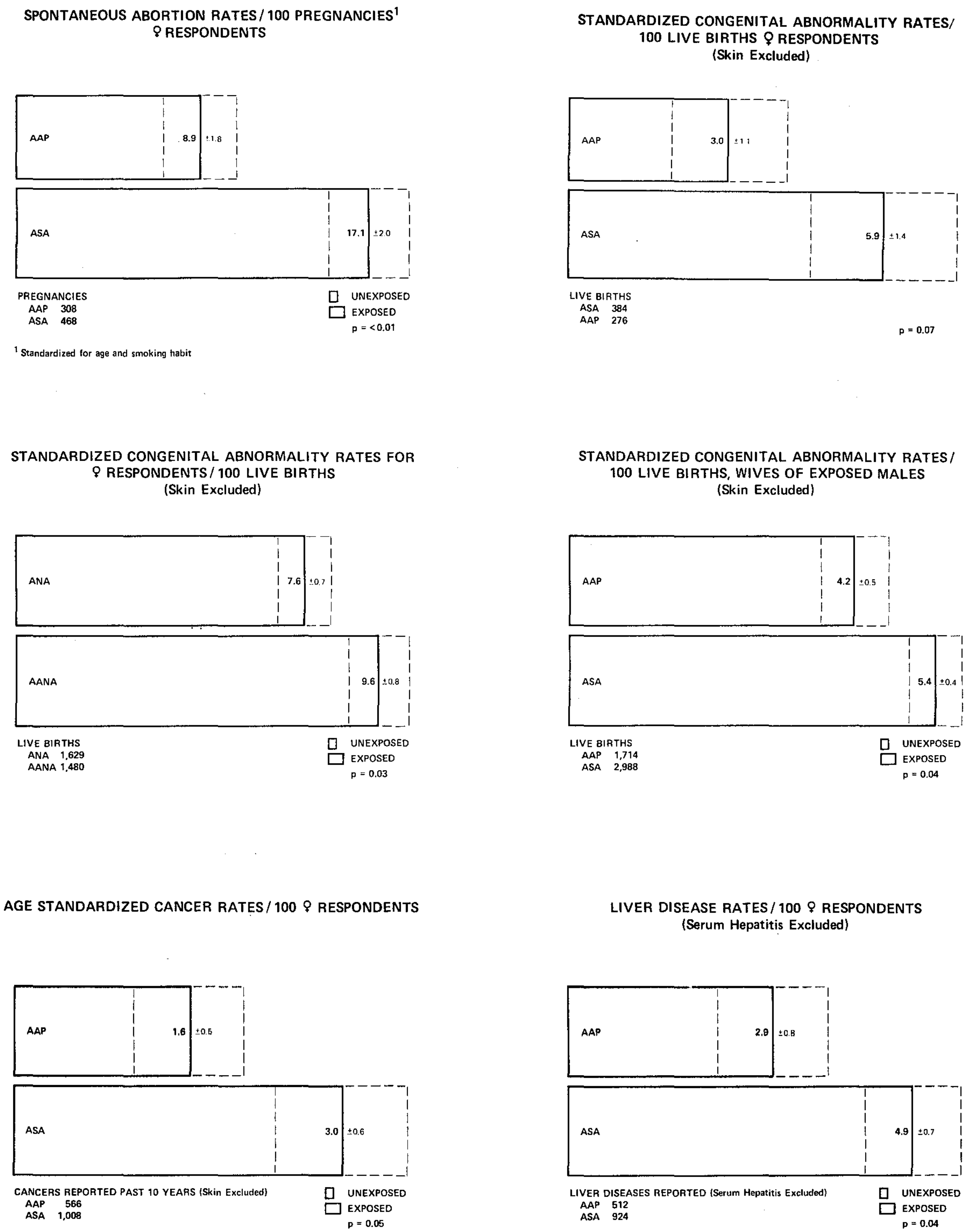

Fig. 1 SELECTED FINDINGS OF ASA EPIDEMIOLOGICAL SURVEY

Key: ASA American Society of Anesthesiologists
AAP American Academy of Pediatrics
ANA American Nursing Association
AANA American Association of Nurse Anesthetists

D. Responses to the Problem of Potential Toxicity of the Inhalation Anesthetics

The American Dental Association (ADA) has recognized the possibility that occupational exposure to anesthetics, including N_2O, present in the air in the treatment room could impose health hazards on dental personnel. In February 1976, the ADA appointed an Ad Hoc Committee on Trace Anesthetics as a Possible Health Hazard in Dentistry. The membership of this committee is comprised of dentists and other personnel with areas of special interest and expertise relating to occupational exposure. It is apparent that the American Dental Association is concerned about personnel exposure to the inhalation anesthetics and is interested in establishing mechanisms for effectively coping with the problem.

The dental Ad Hoc Committee,[15] as well as the corresponding Ad Hoc Committee of the American Society of Anesthesiologists,[3] has recommended use of appropriate control measures, whenever inhalation anesthetic agents are administered, to maintain the lowest reasonably achievable concentrations. The Federal government is also interested in minimizing health risks associated with occupational exposure to the inhalation anesthetics. A standards criteria document[16] with recommended control measures has been drafted by the National Institute for Occupational Safety and Health. This document recommends regulation of occupational exposure. It is presently under review by the Occupational Safety and Health Administration of the United States Department of Labor, and if approved, will be enacted into law under the Occupational Safety and Health Act. It is thus likely that control measures, including leak testing, scavenging, air monitoring, and record keeping will be required in all locations where inhalation anesthetics are employed.

III. CONCENTRATIONS OF INHALATION ANESTHETICS IN THE DENTAL SUITE

Concentrations of waste inhalation anesthetics in the operatory air have been the subject of several reports. In the absence of control measures, the air contains from 500 ppm to over 6,700 ppm N_2O,[17] with proportionately lower concentrations of any other administered anesthetic agents.[18] These concentrations are inhaled by all exposed personnel.

Methods of reducing N_2O and halothane in the operatory air have been presented. Swenson[19] employed the circle absorber and also the nonrebreathing valve in combination with a nonpermeable throat pack and other control measures to reduce N_2O from 1955 ppm without control to a minimum concentration of 172 ppm. Allen and Scaramella[20] described use of the modified Mapleson D (Bain) breathing system with scavenging to achieve a significant reduction of N_2O. Other workers have suggested the use of various devices in an attempt to reduce exposure, but the extent of reduction obtained is not reported. In the present studies, the N_2O inhaled by a series of dentists was reduced from uncontrolled values of 900 $\pm$ 130 ppm to minimum levels of 14 $\pm$ 1.5 ppm, employing methods to be described.

In the absence of control measures, high concentrations of N_2O may be found in all rooms of the dental suite. The waiting rooms and offices, even the closets and restrooms, frequently contain more than 200 ppm N_2O.

Because of the high frequency of use of N_2O in dentistry, this agent is given special consideration in the present publication. However, the methods described are applicable to other inhalation anesthetics, such as halothane and enflurane, when administered to the patient together with N_2O.

IV. SOURCES AND DISTRIBUTION OF INHALATION ANESTHETICS IN THE DENTAL SUITE: ROLE OF AIR-CONDITIONING SYSTEMS

The sources of N_2O in the operatory air include leakage from the anesthesia machine, from the nasal mask, and the patient's mouth (Figure 2). Nitrous oxide may also enter the operatory from adjacent rooms via the window, door, air-conditioning inlet or from the dental suction machine when the exhaust is not vented to a safe disposal site outside the building. Other areas in the suite are polluted by leakage from the operatory and by distribution via the air-conditioning system. The air in a given suite may thus contain N_2O issuing from an adjacent suite where N_2O is in use.

In the absence of scavenging, the most important source of environmental N_2O is the normal gas flow from the anesthesia machine escaping into the room air via the relief valve and around the perimeter of the nasal mask. A secondary source is the patient himself. At the end of the anesthetic, when the gas is turned off, the approximately 30 liters of N_2O which have been absorbed by the patient are rapidly exhaled. Leakage from the patient also occurs constantly during mouth breathing, conversation, and laughter.

Another important and variable source of N_2O is leakage from the anesthetic machine, both in the high-pressure and low-pressure systems (Figure 2). The high-pressure system includes components located between the high-pressure N_2O source and the flowmeters where leakage occurs in worn wall connectors, loose high-pressure hose connections, and in deformed compression fittings. The low-pressure system includes all parts located between the flowmeters and the patient. Leakage occurs here in loose, defective, or missing gaskets and seals; worn or defective bags and breathing hoses; loosely assembled or deformed slip joints and threaded connections; and in loose flowmeter tubes. Another significant source of leakage is improperly designed anesthetic machines and scavenging equipment.

When leakage from the anesthesia equipment is well controlled, the N_2O concentrations are highest in proximity to the nosepiece. The concentrations present in this location are soon diluted by mixing with the room air. Significant mixing results from turbulence caused by movement of personnel and by the air-conditioning system. However, mixing is never complete. Even during use of the most effective control measures, marked short-term variations in N_2O concentrations are usually demonstrable. Figure 3 shows a continuous recording of N_2O concentrations measured in the operatory air during oral surgical procedures in two patients. In this figure, all N_2O control procedures were in effect, sampling was accomplished at the dentist's shoulder, and gas analysis was performed via a rapid N_2O analyzer (described later). Even the marked variations in concentrations shown, with peaks greater than 200 ppm, are limited by the recording system. By employing an averaging procedure (described later), the concentration present for the 61-minute period of N_2O administration is 47 ppm N_2O.

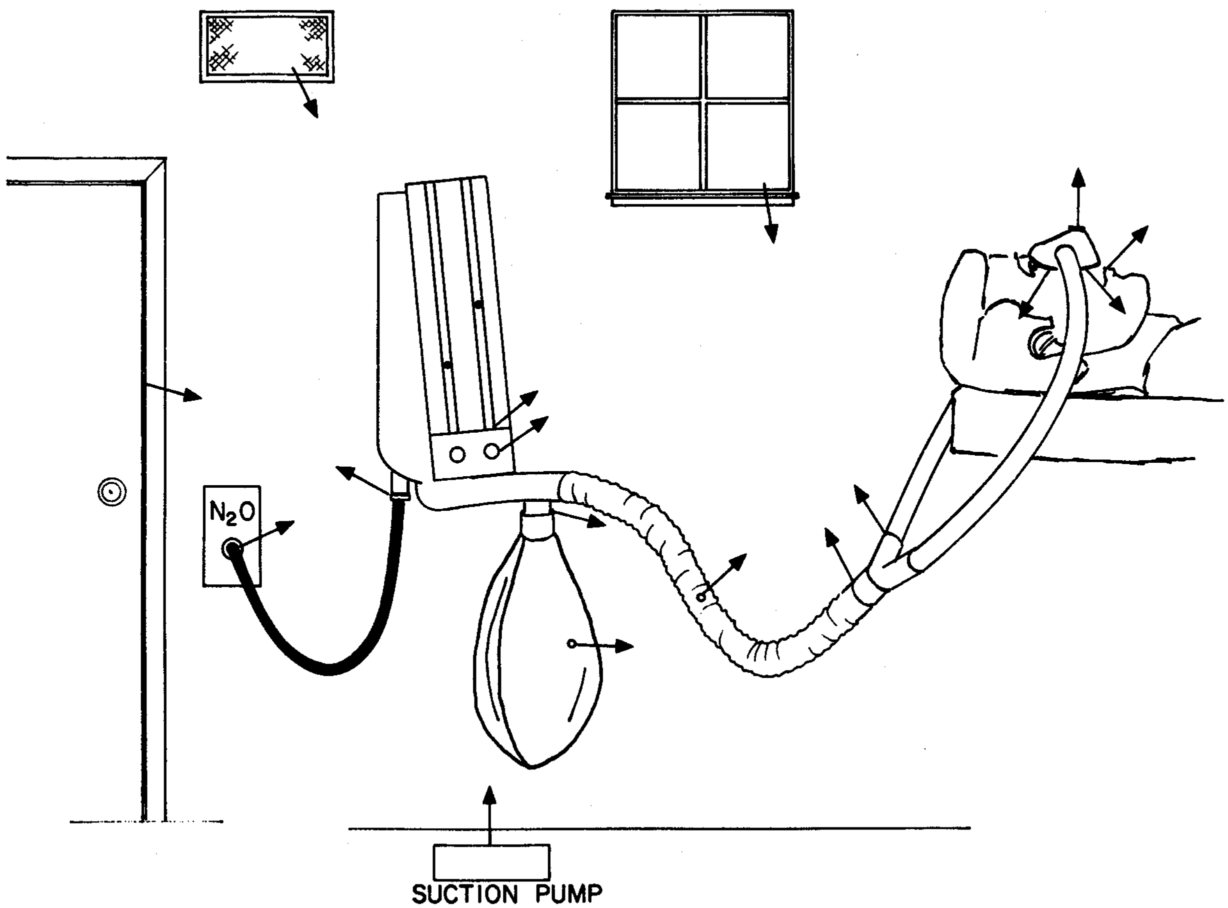

Fig. 2 SOURCES OF N_2O IN OCCUPATIONAL EXPOSURE

Arrows indicate leak sources frequently found in the operatory.

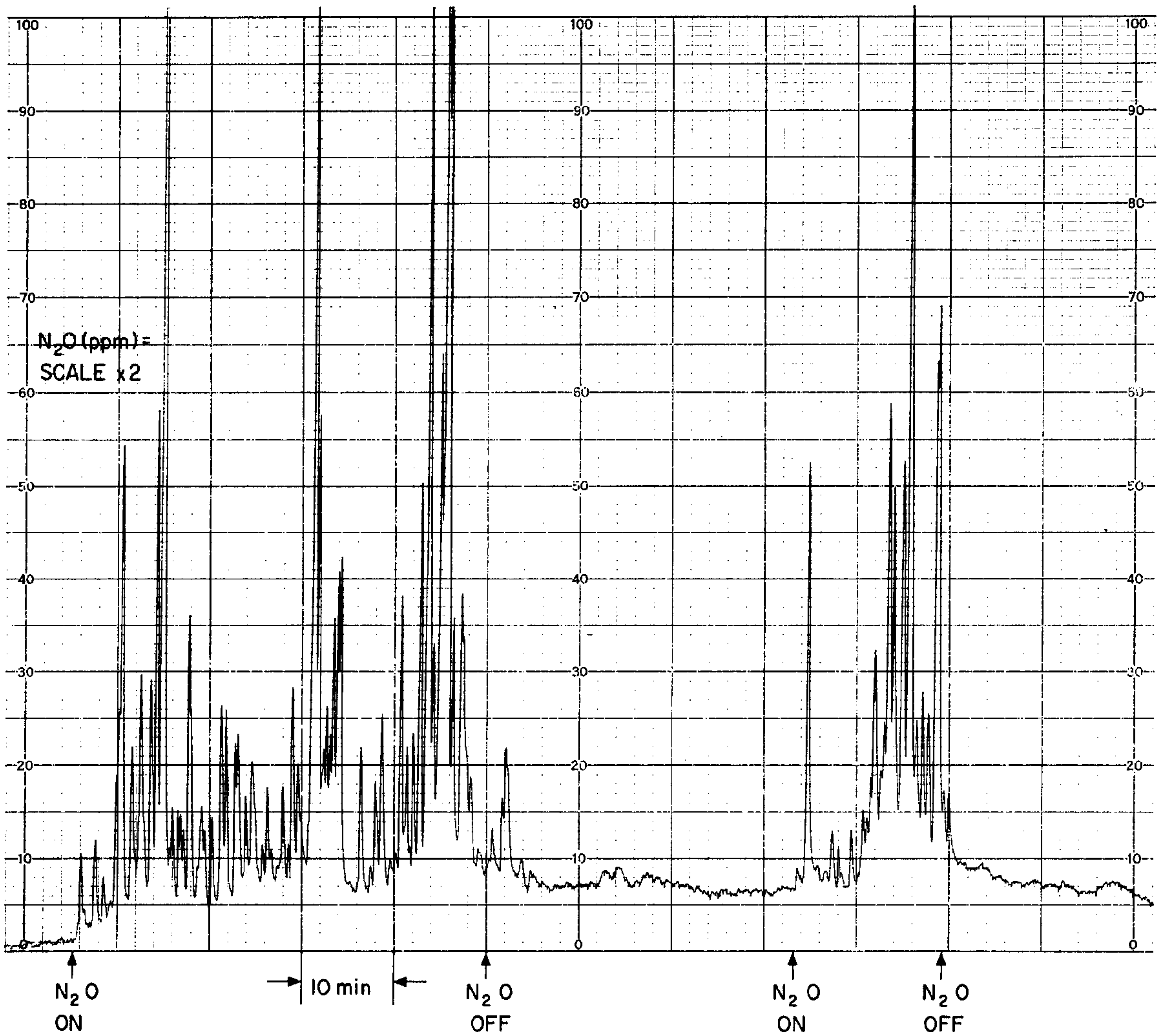

Fig. 3 VARIATIONS IN N_2O CONCENTRATIONS MEASURED IN THE BREATHING ZONE OF DENTIST

Fresh air dilution by the air-conditioning system is a factor in reducing the concentrations of N_2O present in the dental suite in areas away from the nosepiece.[1,21] The air-conditioning system most usually employed in dental operatories is the recirculating type (Figure 4). In recirculating systems, a proportion of the air which is exhausted from the room is vented to atmosphere; the remainder is mixed with fresh air and recirculated back into the room. Any N_2O present in the exhausted air is also recirculated. Increasing the proportion of fresh air decreases the recirculated N_2O. In "one pass" nonrecirculating systems, all of the intake air is exhausted outside the building. Unless heat exchangers are employed, such systems are expensive to operate at the usual air exchange rates provided, i.e. 10-25/hr.

Air-conditioning systems encountered in the present studies appeared to play a minor role in the concentrations of N_2O which were inhaled by the personnel. The air samples for analysis were obtained close to the nosepiece where the primary determinant of the N_2O concentrations present is the rate of leakage of concentrated N_2O mixture from the patient and the nosepiece. In this location, the N_2O concentrations were very much higher than elsewhere in the room.

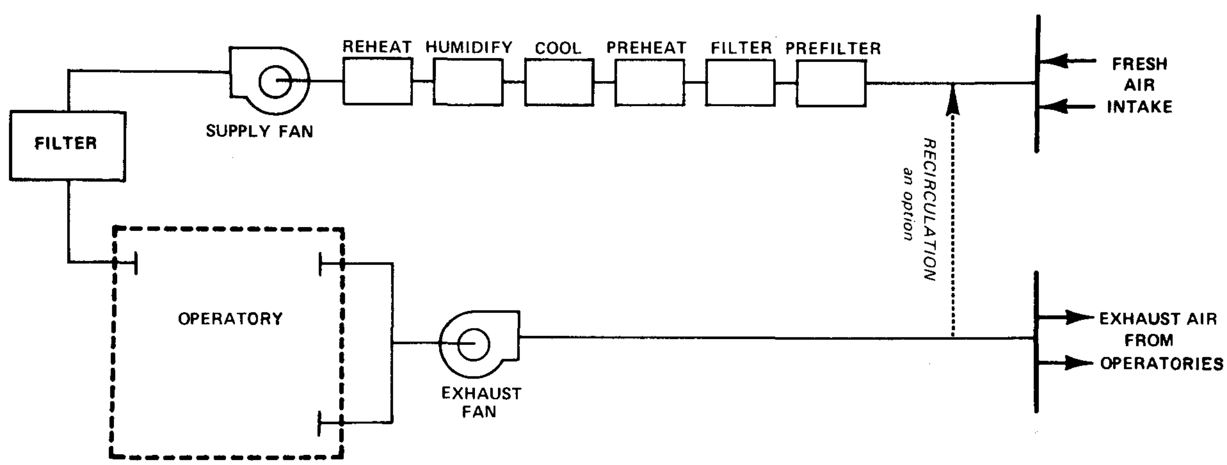

Fig. 4 AIR-CONDITIONING SYSTEM

V. PRIMARY METHODS

The present studies compare concentrations of N_2O present in air samples obtained under various conditions within the breathing zone of the dentist and his assistants. The conditions include performance of operative dentistry under N_2O analgesia. In each operatory, concentrations of N_2O present in the operatory were first established in air samples obtained during the use of the dentist's routine techniques and analgesia equipment. Subsequent samples were obtained employing the control measures designed to reduce the waste gas concentrations. These measures included use of a relatively gas-tight analgesia machine and a specially designed scavenging nosepiece.

A. Operatories Studied.

The eight operatories studied were located in the San Francisco Bay area and were occupied by four general dentists,* two pedodontists, and four oral surgeons.

The dentist's usual anesthesia machine was employed (Dupaco, McKesson, Ohio, etc.) with breathing circuit arranged as shown in Figure 5. Control measurements were obtained with the dentist's usual mask, which was normally provided by one of the above manufacturers.

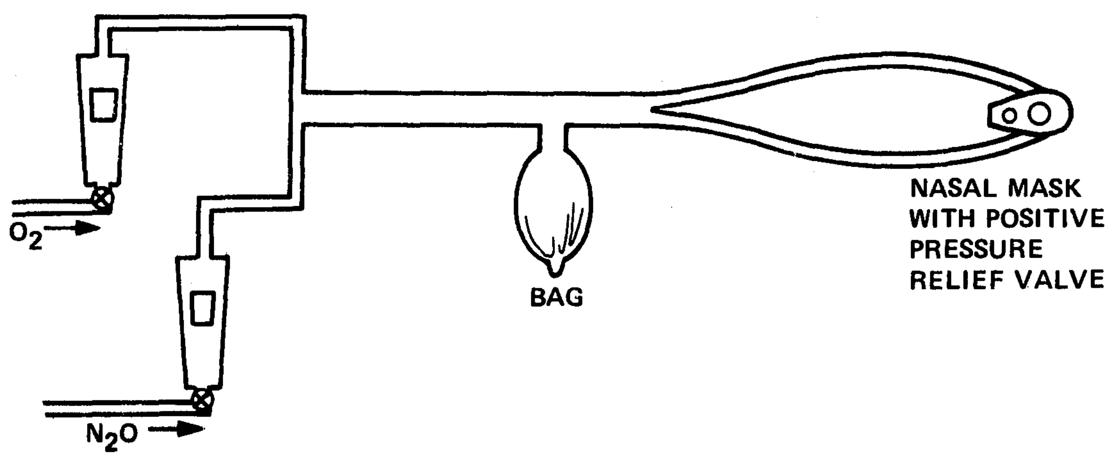

Fig. 5 TYPICAL DENTAL ANALGESIA MACHINE

Without scavenging, exhaled gases escape from the mask and enter the room air.

*One general dentist treated many children. His suite provided data both for the general dentist and the pedodontists.

The general dentists and the pedodontists employed extremely light levels of analgesia (also referred to as psychosedation) secured with N_2O, usually in combination with regional block. The nasal mask was loosely applied so that room air diluted the inhaled gas mixture. This mixture usually included N_2O at 2 to 4 l/min with O_2 at 3 to 4 l/min. With these techniques and under the state of analgesia achieved, patients usually were sedated, relaxed, and responsive to spoken words while maintaining consistently active pharyngeal reflexes. The patients were operated on in the semireclining position in an adjustable dental chair. The dentist usually worked seated, near the patient's head and on the right side. The assistant usually worked from the patient's left side. In the pedodontists' operatories, the patients usually did not converse and they frequently watched a television program. Some of the general dentists maintained dialogue with the patient as an aid in assessing the level of analgesia.

In the operatories of both the general dentists and the pedodontists, where the anesthetic depth never exceeded light analgesia, and conversation was scanty, N_2O did not usually escape from the patient's mouth. The tongue remained in contact with the soft palate, thus isolating the oropharynx from the nasopharynx. This achieved a gas-tight physiologic seal, except during mouth breathing and coughing, speech, or laughter.

The oral surgeons' patients were asleep to the point of unresponsiveness to voice, but with intermittently active reflexes, such as laryngeal, pharyngeal, and swallowing. The drugs administered usually included premedication with fentanyl, diazepam, or pentazocine, induction with methohexital, maintenance with N_2O/O_2 supplemented with small additional doses of methohexital. Regional block was also employed. The patient was treated in the reclining position on the operating table. The anesthetist sat at the head of the table with the dentist standing at the patient's right side and the assistant at the patient's left. The anesthesia machine was located at the anesthetist's right The nasal mask was usually applied snugly with the intent of securing a gas-tight seal; however, some oral surgeons preferred a loosely fitted mask.

In the oral surgeons' operatories, a throat pack of damp gauze was inserted deep in the oropharynx in order to keep foreign material out of the airway while still permitting nasal breathing. The patient tolerated the pack as a result of the deeper levels of analgesia employed by the oral surgeons as compared to the general dentists and pedodontists. The pack sealed the pharynx less efficiently than the physiologic seal observed in the patients of the other dentists. The resultant leakage was marked and readily observed when the sampling probe of the N_2O analyzer was held near the patient's mouth. When the oral surgeon observed such leakage, he was apt to try for a more gas-tight fit of the throat pack.

B. Gas Sampling Procedures

Equipment for gas collection was arranged to aspirate air samples from strategic locations in the operatory (Figure 6). Details of the sampling pumps are shown in Figure 7. The sampling catheters consisted of vinyl tubing 0.044 x 0.065 in. connected via sampling pumps to empty into gas-tight bags. With the bags filled at a constant rate for the duration of each case, a time-weighted, averaged sample was obtained.

The sampling pumps were turned on approximately when the N_2O flowmeter was turned on; they were turned off at the end of the case.* The samples stored in the gas-tight bags were analyzed for N_2O concentration. Following analysis and prior to subsequent use, all bags were repeatedly flushed with N_2O-free air.

"Breathing zone samples" are representative of the N_2O inhaled by the dentist and are obtained from a frontal area within 6 to 10 inches of his nose where N_2O concentrations are usually at a maximum. Such samples were conveniently obtained at the dentist's shoulder, or at his eyeglass frame or headlight. In certain cases, the sampling catheter was suspended from the overhead light fixture, again within 6 to 10 inches of the dentist's nose. "Room samples" were obtained in the pathway of the air-conditioning exhaust.

Sampling directly in the pathway of the dentist's expired air, such as at the nares, was avoided in samples which were analyzed by infrared spectroscopy (described below). Otherwise, the exhaled water vapor and CO_2 could influence the results.

C. The Infrared N_2O Analyzer

The N_2O analyzers employed in the present studies were developed especially for use in air monitoring programs. The principle of operation (Figure 8) is absorption of infrared light (IR) at a wavelength specific for the gas under analysis, 4.45 microns for N_2O. As shown in Figure 9, a fan continuously aspirates the air and passes it through the sampling cell of the analyzer. An infrared light beam is simultaneously transmitted through the same cell. Variations in concentrations of N_2O result in proportionate changes in the quantity of transmitted IR energy. This is sensed by the detector, and then amplified and displayed. Response time of the N_2O analyzers is rapid (2-20 sec), depending on the ratio of sampling flow rate to cell volume. With the analyzers employed, lower limit of detection of N_2O is approximately 1 ppm; upper limit is 100-2,000 ppm. Calibration techniques included the use of commercially available standard mixtures of N_2O in gases which do not absorb IR energy, such as air,

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*In later studies, when it was recognized that the flowmeter for O_2 might be on significantly longer than the flowmeter for N_2O, sampling was accomplished exclusively when the N_2O flowmeter was on.

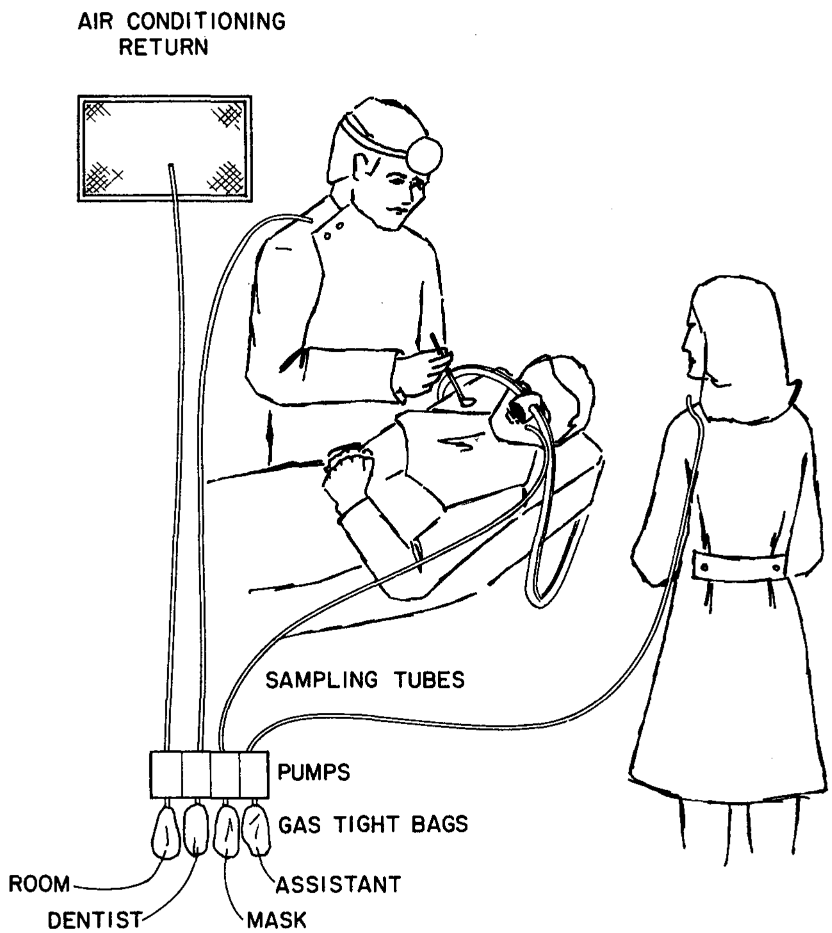

Fig. 6 N_2O SAMPLING SYSTEM

Sampling catheters were arranged for the continuous aspiration of samples in strategic locations, with temporary storage of samples in gas-tight bags.

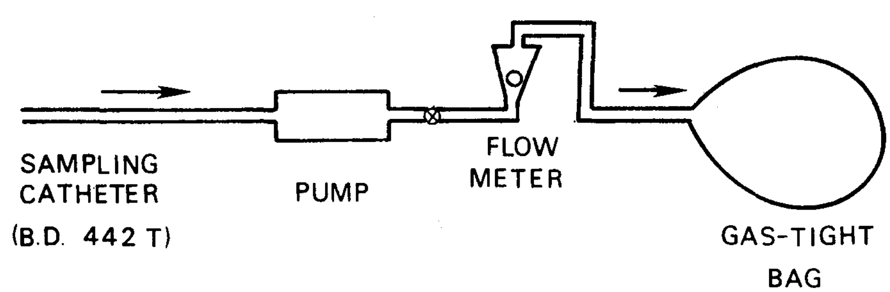

Fig. 7 DETAIL OF SAMPLING SYSTEM

Flowmeter permits monitoring to assure constant sampling flowrate.

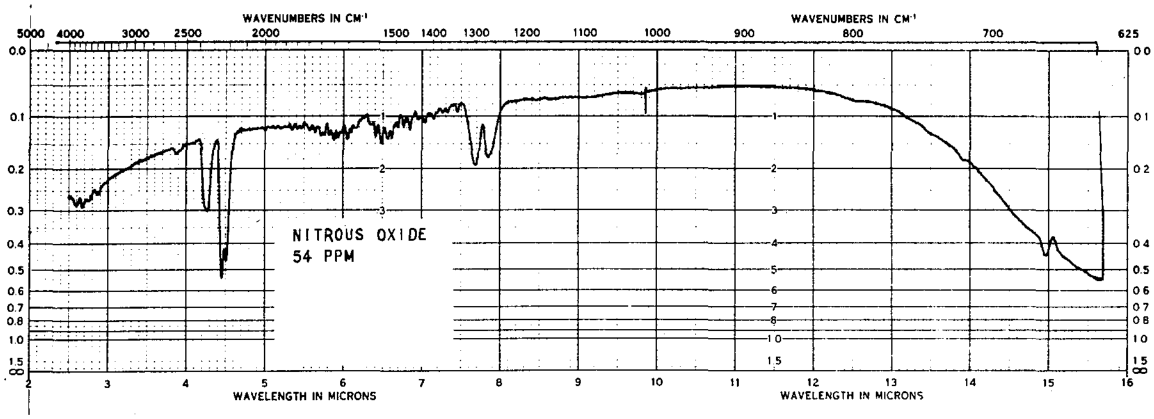

Fig. 8 INFRARED ABSORPTION SPECTRUM FOR N_2O

The most marked absorption for N_2O occurs at 4.45 microns.

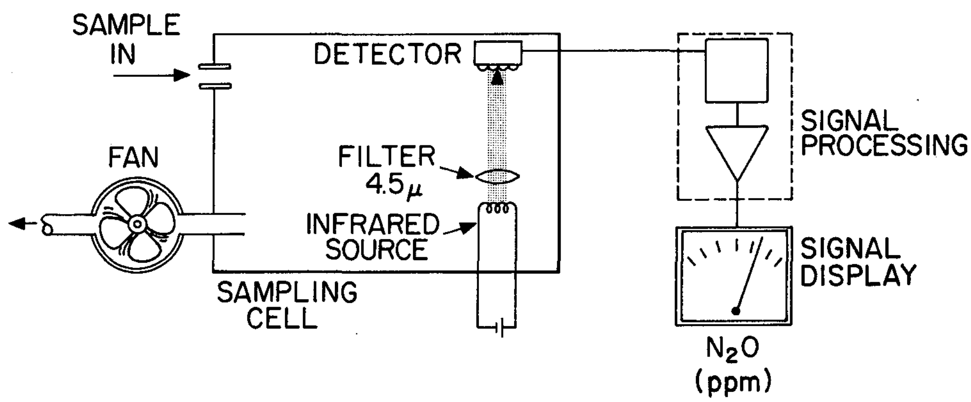

Fig. 9 INFRARED ANALYZER FOR N_2O

Fan circulates air sample through sampling cell. N_2O in sample reduces amount of filtered infrared light reaching detector in proportion to concentration, and is indicated on display device.

N_2, or O_2; and a dilution method (Figure 10) in which a small quantity of pure N_2O (20 cc) is injected into a gas-tight box or bottle of large capacity (100 l). Zero is established with any of the non-IR absorbing gases. Total system accuracy is estimated to be within $\pm$ 5 percent of the N_2O concentrations reported in the present studies.

The possibilty of interference in gas analysis by IR spectroscopy must be considered. Carbon dioxide presents a strong absorption peak at 4.43 micra which is close to the N_2O peak at 4.45 micra. Moreover, water vapor may fog optical components. In the present studies, analytical errors due to CO_2 and water vapor were avoided by sampling away from the expired air stream of the personnel. Evidence that interference was insignificant was obtained in parallel gas analyses by gas chromatography.

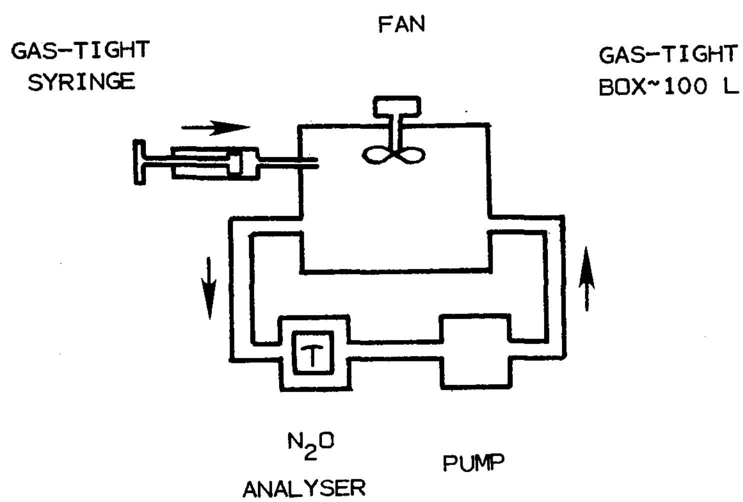

Fig. 10 DILUTION METHOD OF CALIBRATING N_2O ANALYZERS

Calibration standards are custom mixed.

D. Primary Control Measures

1. Testing the Equipment for Leakage.

In a number of treatment rooms, high concentrations of N_2O were found to result from leakage in the anesthetic equipment. Leak sources commonly encountered are detailed in a preceding section.

Detection of leakage in the high-pressure components of the N_2O system was accomplished by observation of the pressure gauge for the central N_2O supply. With the cylinder valves and flowmeters turned off at the end of the work day, tight systems held pressure overnight with less than 10 percent loss of the normal working pressure, approximately 50 psig.

Leakage in the low-pressure components of the anesthesia machine was easily determined (Figure 11). The breathing bag was tested on the anesthesia machine by overfilling with O_2 to several times its normal volume. Palpation of the surface revealed any significant leakage. Breathing hoses and the other low-pressure components were leak tested as a unit. Preparations for this test included removing the bag from the machine and adapting a blood pressure gauge to the bag outlet. The breathing connections of the nasal mask were connected. This test condition resulted in an air-tight, noncompliant pneumatic system of small volume.

Following the above preparations, leak testing of low-pressure components was performed by either of two methods. The first method was to turn on a low-range O_2 flowmeter at a rate sufficient to maintain a constant pressure of 30 mm Hg. The flowrate, when equilibrated with the leak, provided a quantitative measure of the leak rate. A tight machine leaked less than 100 cc/min. at 30 mm Hg. Precautions in performing this test included careful observation of the pressure gauge since over-pressurization could damage the gauge.

The second test was employed when the O_2 flowmeter did not have a low-calibrated range. This method consisted of closing the low-pressure system as described above. The system was then filled with O_2 to a pressure of 30 mm Hg. The O_2 was then turned off. The machine was considered tight if it lost less than 10 percent of its pressure over a 30-second period of observation.

Machines which were equipped with O_2 flush valve, low-range O_2 flowmeter, and built-in pressure gauge were easiest to leak test because all components were attached as for routine analgesia, including the breathing bag. The O_2 flowmeter was set for 100 cc/min.; the outlet hoses at the nosepiece were occluded by kinking; and the flushvalve was employed to pressurize the system to 30 cm H_2O. When the machine was tight, the 30 cm H_2O pressure would hold or slowly increase.

The demand-flow gas machines encountered in the present studies leaked considerably, were considered irrepairable, and were excluded from use.

It is important to note that the leak testing procedures employed in the present studies are not suitable for all analgesia machines. The suggested pressurization test may damage certain equipment. The dentist is advised to check with the manufacturer to determine the most suitable leak testing procedures for his own equipment.

Leakage, once identified, must be localized and repaired. While an outside servicing concern may be needed to correct obscure leakage, the dentist might initiate a preliminary search by applying soap solution to suspected leak sites or direct immersion of waterproof pressurized components (Figure 12).

2. Venting the Waste Gases; Suction Pumps

In most of the offices studied, the existing suction system was adequate for scavenging and for removal of secretions as indicated by insignificant variations in vacuum flow and pressure under working conditions. Variations in vacuum were minimized by carefully planning the site of entry of the scavenging line into the vacuum system. The best site was usually close to the pump. Where suction was inadequate, a separate system with a fan-type pump was installed for scavenging.

To avoid contamination of the room air with N_2O, all suction pumps aspirating air from the patient's mouth or from the scavenging mask were vented via gas-tight lines to a safe disposal site outside the building. This must be away from air inlets, windows which are opened, and other areas occupied by personnel. In the present studies, the suction machine was usually vented at roof level.

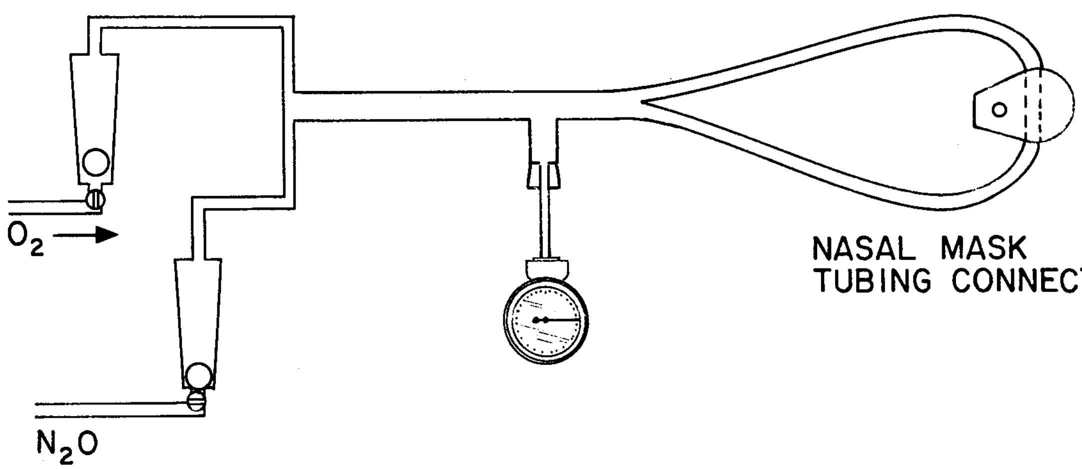

Fig. 11 LEAK TESTS FOR LOW PRESSURE N_2O SYSTEM

Bag (not shown) is tested by over-inflating with O_2 and palpating its surface. With bag removed, other components are tested as a unit by establishing that flowrate of O_2 which maintains a static pressure 30 mm Hg.

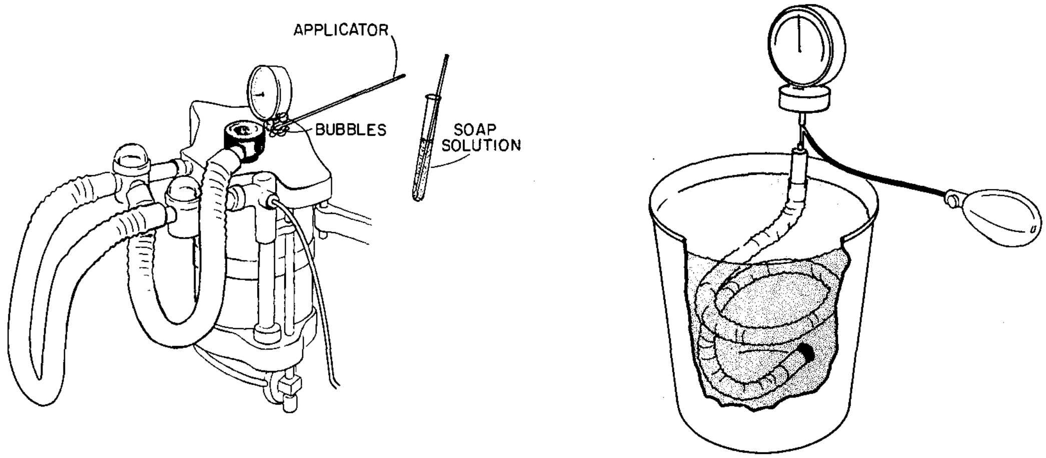

Fig. 12 LEAK LOCALIZATION PROCEDURES

When auscultation and palpation fail to reveal leak sites, pressurized components can be tested with soap solution and immersion tests.

Failure to dispose of the effluent at a sufficient height above ground level invited the possibility of reentry of gas into the suite. Such reentry could be seemingly unpredictable because of its occurrence only under certain wind conditions.

Alternative disposal routes should be considered. The exhaust of the air-conditioning system could be employed when this system does not recirculate.[1] Whatever disposal pathways are utilized, those methods which impose a slightly negative pressure into the breathing system during exhalation tend to minimize leakage from sources such as the low-pressure components of the breathing circuit, especially the nosepiece,and also from the patient's mouth. On the basis of the present studies, it seems likely that the lowest room concentrations will be maintained when waste gases are vented via suction.

Vacuum pumps exposed to anesthetic gases met necessary fire codes and standards.[22] Turbines located in the gas stream were spark proof and motor brushes and switches were located out of the gas stream.

3. Scavenging Nasal Mask

The newly developed scavenging nosepiece employed consists of a compact double mask system (Figure 13). The inner mask is contained within the slightly larger outer mask and a slight vacuum is present in the space between masks. This vacuum scavenges gases exhaled by the patient as well as any excess of gases from the analgesia machine that might leak around the edges of the inner and outer masks. The two larger hoses, 3/8 in. internal diameter (i.d.), supply the anesthetic gases to the inner mask. The two smaller hoses, 1/4 in. i.d., open into the space between layers and are for scavenging.

The relief valve has two major components. The first is a screw-adjustable sleeve which regulates the flow of gases from the anesthesia machine into the space between masks. Correct adjustment insures preferential inhalation of gases from the anesthesia machine and is indicated by an appropriately filled breathing bag. The second component is a nonadjustable, disc-type relief valve which is normally closed. This valve admits room air into the mask in case of insufficient gases in the breathing circuit. With normal breathing, a closely fitted mask, and adequate gas supply, the patient inhales exclusively from the breathing circuit. Anesthetic gases are removed only during exhalation. Pressure within the mask is approximately atmospheric and is limited to maxima -2 to -3 cm H_2O during inhalation, +0.5 cm H_2O during exhalation.

The vacuum flowrate is approximately 45 l/min. This is the optimal flow necessary to prevent any significant N_2O leakage into the room air, even when the mask is detached from the patient and supplied with 4 l/min each N_2O and O_2.

The prototype mask shown in Figure 13 was employed in the results and discussion to be presented with Tables 2 and 3. Further studies were conducted in an oral surgical suite in order to confirm the efficiency of the production version of the scavenging mask shown in Figure 14. Results and discussion of studies with this version will be presented in Table 4. In the latter studies, air sampling procedures were consistent with methods to be recommended in the air monitoring program. These studies were also designed to determine the feasibility of meeting the suggested, reasonably achievable N_2O concentrations under circumstances of companion operatories simultaneously in operation and sharing the same recirculating air-conditioning system.

Breathing zone samples were obtained (via catheter which terminated at the dentist's should) over a sampling period of at least 1 hour and including several cases. The sampling catheter was connected to a sampling pump to fill a gas-tight bag. The sampling pump was turned on when the N_2O flowmeter was on, off when the N_2O flowmeter was turned off. At the end of each workday, the N_2O concentration present in the bag sample was determined by IR spectroscopy.

The time weighted average N_2O concentration was determined for a series of such bag samples. Calculations first took into account the daily variations in sampling period by establishing a product for each bag, N_2O (ppm) of contents

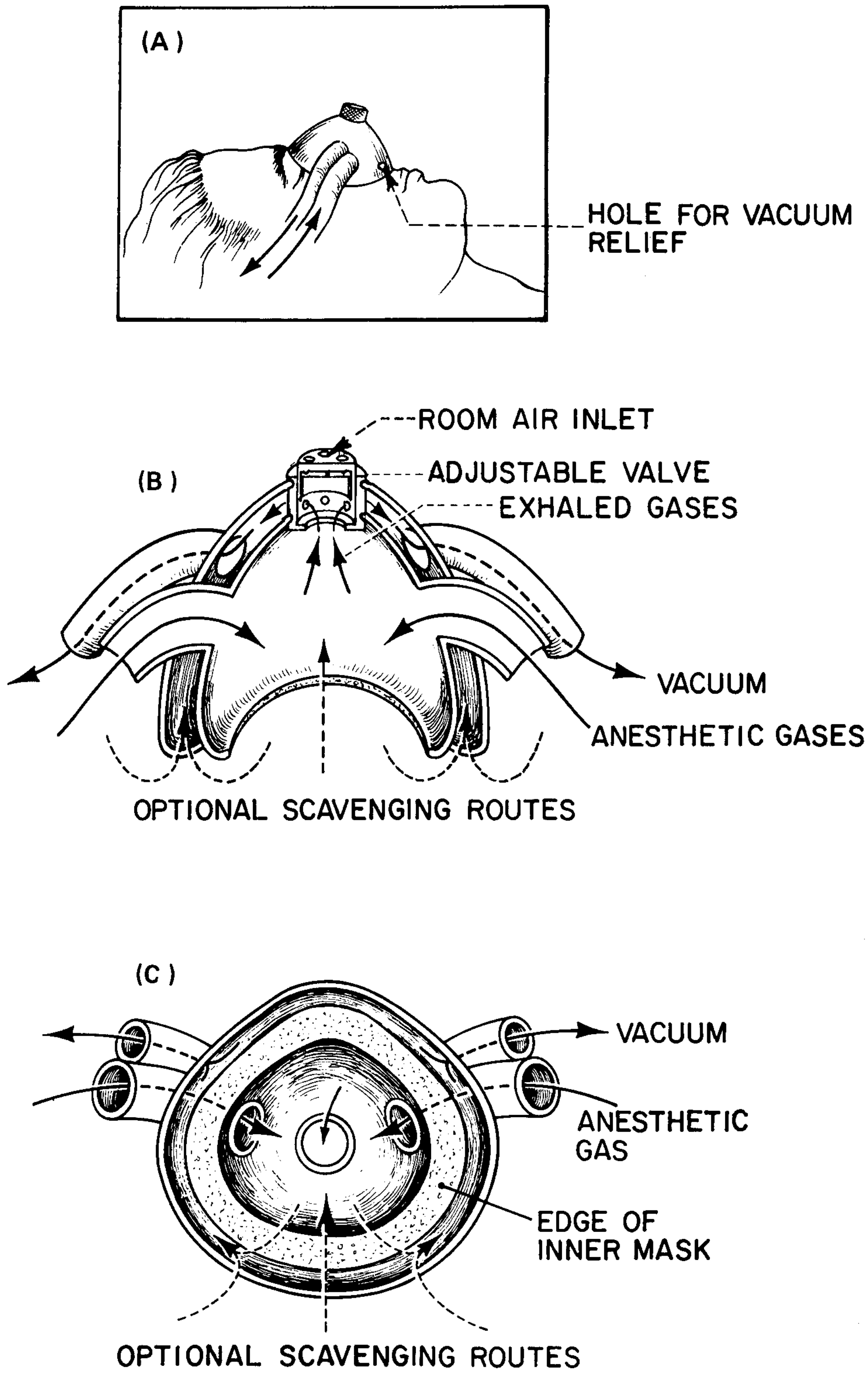

Fig. 13 SCAVENGING NASAL MASK, EXPERIMENTAL MODEL

Double mask with suction in space between masks minimizes N_2O leakage near the patient's mouth.

multiplied by sampling time (min). A series of such products were summed, to get a number sufficient for a total sampling time of 1 hour or more. This series sum was divided by the total sampling time for the series of bags.

Day No.	Sampling Time (min)	N_2O (ppm)	ppm x min
1	a	b	ab
2	c	d	cd

TWA = (ab + cd + etc) ÷ (a + c etc.)
(a + c etc.) to equal 1 hour or more.

4. Minimizing Speech

With the patient under N_2O analgesia, use of the voice resulted invariably in the escape of N_2O from the mouth in an area not only difficult to scavenge, but also close to the breathing zones of dental personnel. Even when the dentist depended on verbal communication as a means of determining the depth of analgesia, speech could be safely reduced and excessive speech was discouraged.

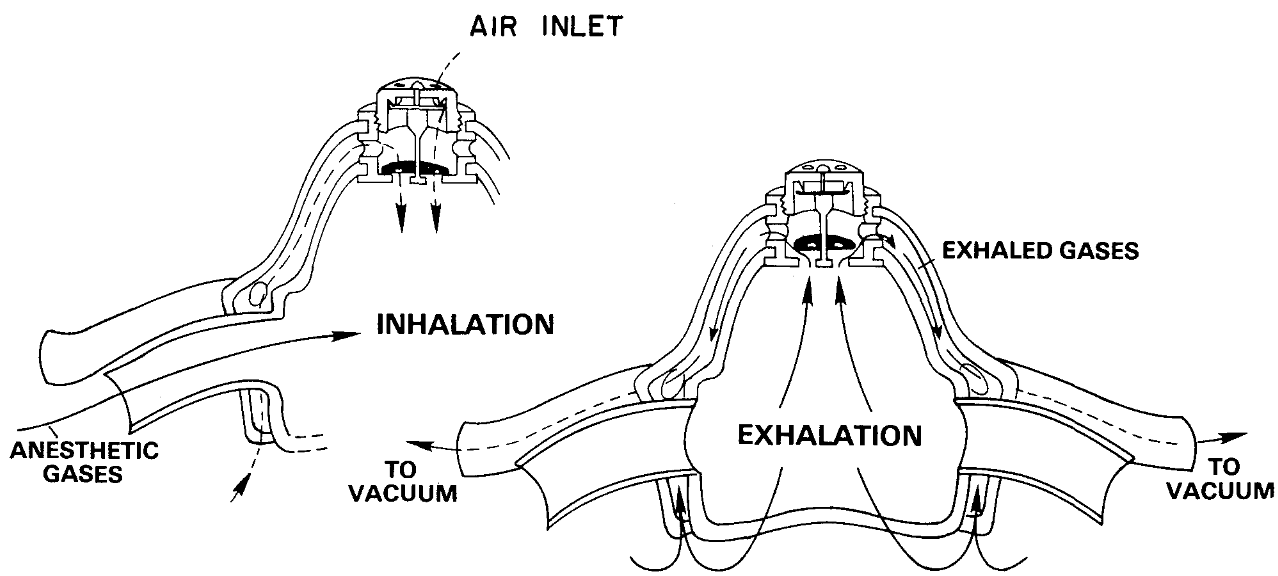

Fig. 14 SCAVENGING NASAL MASK, PRODUCTION MODEL

Production model is simplified by eliminating adjustable sleeve.

5. Air Monitoring Program

The air monitoring program is an indispensible feature of the N_2O control program. Despite a conscientious effort to apply the other control measures, some N_2O leakage is invariably present and a significant amount is prone to occur in unexpected places where detection is difficult. N_2O is nearly odorless and even relatively large leaks may be inaudible. The only practical method of detection is to monitor the concentration of N_2O in the room air.

The program to be presented later was designed on the bases of all experience gained during the studies which have been presented above. Important features include air samples obtained within the breathing zone of the dentist (a frontal area within 6-10 inches of the nose) during the time the N_2O flowmeter is on.

VI. RESULTS AND DISCUSSION OF PRIMARY METHODS

Table 2 shows the number of dentists and cases studied; the patients' age, weight, and sex; and the sampling time and flowrates of the gases employed. These data were obtained in a total of 157 routine cases relating to various dental specialities.

N_2O concentrations shown in Table 3 were obtained in the eight operatories. With conventional masks, mean concentration of N_2O inhaled by the dentists was 900 $\pm$ 55 ppm; their assistants inhaled 560 $\pm$ 97 ppm; the average room concentration was 300 $\pm$ 26 ppm. When the scavenging mask was employed in combination with relatively leakproof equipment, the dentists' inspired concentration was reduced to 31 $\pm$ 2.5 ppm and the assistants' to 17 $\pm$ 1.7 ppm, both representing a reduction to 3 percent of the original exposure level. The average concentration present in the room was 14 $\pm$ 1.2 ppm. Of the three dental specialties studied, the lowest breathing zone concentration (21 $\pm$ 1.9 ppm) was achieved by the four general dentists. Results with the two pedodontists were somewhat higher, 33 $\pm$ 4.0 ppm. The patients treated by the general dentists and the pedodontists were awake and any oropharyngeal communication with the room air was physiologically sealed. In the two oral surgeons' operatories, a higher concentration (36 $\pm$ 4.1 ppm) was found. At the slightly deeper levels of analgesia employed by these dentists, the physiological oropharyngeal seal was less consistent and the throat pack provided uncertain sealing.

Results of studies completed in the adjacent, working, oral surgical operatories employing production versions of the newly developed scavenging mask are presented in Table 4. A total of 15 days of sampling, including 47 oral surgical cases yielded 687 minutes of sampling. The time-weighted average N_2O concentration was 31 $\pm$ 4.8 ppm, a value which closely approximates those obtained for the oral surgeons employing the primary control measures (low-leakage equipment and prototype versions of scavenging mask) in the studies shown in Table 3.

With dentistry simultaneously in progress in the two operatories, N_2O cross-contamination was evident. It is apparent that, in the larger, multiple chair suites, this phenomenon could cause difficulty in maintaining low concentrations of N_2O. This factor, combined with the difficulty in maintaining the oropharyngeal seal with the throat pack, aggravates the problem of N_2O control in the oral surgeon's suite.

In completing the present studies, several advantages of the scavenging mask became evident. Besides achieving a 29-fold reduction in the dentist's inspired N_2O, the mask was largely procedure-independent and scavenged efficiently regardless of the dentist's techniques. Careful fitting was not required; in fact, scavenging was efficient even when the gas was on and the mask was not applied to the patient's nose. This is in contrast to the Bain/Littell system (described below) which was highly procedure-dependent in requiring careful fitting of the nosepiece in combination with accurate timing in turning the gases on and off. Procedure independent devices, such as the scavenging mask, would be expected to yield the

Table 2

DATA BASE.- STUDIES OF OCCUPATIONAL EXPOSURE TO N_2O IN OPERATORIES OF THREE DENTAL SPECIALTIES

CATEGORIES	NUMBER OF DENTISTS	NUMBER OF CASES	PATIENTS AGE YEARS	PATIENTS WEIGHT KILOGM	PATIENTS SEX M	PATIENTS SEX F	TIME (MIN) N_2O ON	SAMPLING PUMPS ON	MEAN FLOW RATES 1/MIN N_2O	MEAN FLOW RATES 1/MIN O_2
CONVENTIONAL MASK										
GENERAL DENTISTS	4	20	30 ± 3.6	66 ± 2.7	11	9	31 ± 3.0	36 ± 3.5	2.3 ± 0.13	3.4 ± 0.14
PEDODONTISTS	2	17	10 ± 1.1	36 ± 3.9	10	7	27 ± 2.9	30 ± 3.3	2.4 ± 0.10	2.9 ± 0.06
ORAL SURGEONS	2	15	25 ± 2.4	68 ± 4.7	7	8	24 ± 3.1	31 ± 3.5	4.0 ± 0.0	4.0 ± 0.0
SCAVENGING MASK										
GENERAL DENTISTS	4	40	31 ± 1.7	60 ± 1.4	7	33	32 ± 2.2	34 ± 2.2	2.6 ± 0.15	2.8 ± 0.09
PEDODONTISTS	2	17	10 ± 0.91	36 ± 3.0	7	10	19 ± 1.9	22 ± 2.1	2.4 ± 0.08	2.8 ± 0.06
ORAL SURGEONS	2	22	25 ± 2.8	58 ± 2.5	9	13	24 ± 2.6	29 ± 3.0	3.6 ± 0.16	3.9 ± 0.17
SCAVENGING MASK + AIR SWEEP FAN										
GENERAL DENTIST	1	9	12 ± 2.7	56 ± 5.6	Data Not Recorded		30 ± 3.8	34 ± 4.0	2.4 ± 0.14	2.7 ± 0.08
PEDODONTIST	1	9	7 ± 1.2	26 ± 3.5			28 ± 4.4	31 ± 4.6	2.3 ± 0.24	3.0 ± 0.0
ORAL SURGEON	1	8	24 ± 4.7	56 ± 1.7			37 ± 7.0	43 ± 6.1	4.0 ± 0.0	4.0 ± 0.0
TOTALS										
CONVENTIONAL MASK	8	52								
SCAVENGING MASK	8	79								
SCAVENGING MASK + FAN	3	26								

Table 3

RESULTS. – STUDIES OF OCCUPATIONAL EXPOSURE TO N_2O IN OPERATORIES OF THREE DENTAL SPECIALTIES

CATEGORIES	N_2O (ppm) BREATHING ZONE DENTIST	ASSISTANT	AVERAGE IN ROOM
CONVENTIONAL MASK			
GENERAL DENTISTS	775±63	440±52	310±37
PEDODONTISTS	940±92	112±23	280±52
ORAL SURGEONS	1000±130	1600±250	310±47
SCAVENGING MASK			
GENERAL DENTISTS	21±1.9	13±1.3	11±0.79
PEDODONTISTS	33±4.0	8.7±3.3	16± 2.6
ORAL SURGEONS	36±4.1	36±4.4	16± 2.6
SCAVENGING MASK + AIR SWEEP			
GENERAL DENTIST	15±7.0	11±2.6	13± 1.7
PEDODONTIST	9.4±0.87	7.5±0.43	8.4± 1.8
ORAL SURGEON	18±3.6	14±2.0	17± 3.0
TOTALS			
CONVENTIONAL MASK	900±55	560±97	300±26
SCAVENGING MASK	31±2.5	17±1.7	14±1.2
SCAVENGING MASK + FAN	14±1.5	-	13±1.4
REDUCTION OF N_2O			
SCAVENGING MASK VS. CONVENTIONAL MASK	-97%	-97%	-95%
SCAVENGING MASK + AIR SWEEP VS. CONVENTIONAL MASK	-98%		

Table 4

PERFORMANCE OF SCAVENGING MASK IN ADJACENT, WORKING, ORAL SURGICAL OPERATORIES

DAYS OF SAMPLING	NUMBER OF CASES	SAMPLING TIME (MIN)	N_2O IN BAGS (PPM)
15	47	687	31 ± 4.8

$\pm$ S.E.
SAMPLING WITH N_2O ON
2 DENTISTS

most consistent reduction of N_2O concentrations. Acceptability of the scavenging mask, both to the dentist and to the patient, was essentially universal. No safety hazard was noted. Analgesia was conducted approximately as with the dentist's previous techniques, at similar gas flowrates as shown in Table 2.

Studies of concentrations of CO_2 in expired gases were completed with the scavenging mask and the Bain/Littell breathing system. The gas analyzer employed was an IR unit which was designed for breath-by-breath analysis (Cavitron). When the Bain breathing system and the scavenging mask were employed as recommended by their respective manufacturers, inspired CO_2 was approximately zero, and end-tidal values showed evidence of mild retention only for short periods of time, such as following a period of partial airway obstruction or when anesthesia was unusually deep. On the basis of these studies, rebreathing was not demonstrated and evidence is provided that both breathing systems are compatible with normal ventilation.

Several factors were taken into account in arriving at a suggested "reasonably achievable" concentration of N_2O as high as approximately 50 ppm in a time-weighted sample obtained within the dentist's breathing zone when the N_2O flowmeter is on. Under the circumstances of the present studies, N_2O concentrations of 31 ± 2.5 ppm and 31 ± 4.8 ppm were achieved with the newly developed scavenging mask employed in combination with relative leak-free anesthetic equipment. Comparable concentrations have been obtained in the operatories of dentists who have purchased the mask through commercial channels and for whom air monitoring has been provided. The suggested concentration is believed to be achievable in routine practice with reasonable effort.

Conditions prevailing in other operatories not yet studied could create difficulties in maintaining the low N_2O concentrations cited above. Such situations might possibly include multiple-chair analgesia in the same operatory and large buildings in which a single, recirculating air-conditioning system supports several dental suites. Further studies are needed to determine the possible problems existing in such situations.

Design features of the air monitoring program to be recommended are considered in terms of two groups of variables. One group is readily controllable; the other group is relatively uncontrollable.

Uncontrollable variables include:

a. Office scheduling practices. Anesthetic procedures, both local and inhalation, are usually scheduled in random order. The workday may thus contain many or few inhalation anesthetics.

b. Anesthetic techniques. These vary from dentist to dentist and, with a given dentist, case by case. Nitrous oxide and oxygen are delivered to the patient at differing relative lengths of time, with the O_2 usually being turned on variably longer than the N_2O. Also, these gases are administered at variable flowrates, dentist by dentist and case by case.

c. Daily N_2O leakage. Even with an effective control effort, appreciable N_2O leakage occurs, and at a variable rate. As a result, a single air sample obtained during any single case is not necessarily representative.

d. Short-term changes in N_2O concentrations. Changes within a given anesthetic are characteristically rapid (seconds) and marked in amount (hundreds of ppm). Such individual variations may be difficult to interpret.

e. Air exchange rate. Increasing fresh air exchange rate of the air-conditioning system could reduce N_2O concentrations, but a very great and undefined increase would be required; cost would be prohibitive. The necessary alterations are inconsistent with one objective of the N_2O control program, which is to maintain the lowest N_2O concentrations at reasonable cost.

Variables that are controllable include:

a. Personnel sampled. The dentist is the most appropriate person to sample. He usually inhales higher N_2O concentrations than his assistants and he is more apt to remain in the room for the entire duration of N_2O administration.

b. Sampling site. The sampling site is critical in achieving consistent, reproducible results. A frontal site within 6 to 10 inches of the dentist's nose is desirable because it is relevant to inspired concentration and avoids CO_2 interference in the IR analysis of N_2O. Other suitable sites include the eyeglass frame, the personnel-mounted headlight, or the overhead light. Sampling at the nares is inconvenient and unreliable with IR analysis.

c. Timing of samples. Timing is critical in providing a consistent basis for sampling, thus minimizing the effect of the uncontrollable variables. A common denominator of all inhalation techniques is the time the N_2O flowmeter is actually on.

The feasibility of an air monitoring program would depend on the availability of equipment and services for air sampling and analysis (see Appendix B). Air sampling equipment suitable for the collection of time-weighted samples is readily available. One such device (Figure 15) is mailed complete with all components. The monitoring unit is placed in a convenient location, and the sampling catheter is attached to the dentist's shoulder or to the operating light. The built-in timer logs total sampling time. The sample is stored in the integral gas-tight bag.

Infrared analyzers for use by the dentist or his technician are also available and easy to use. With demand, these should become available on a rental basis.

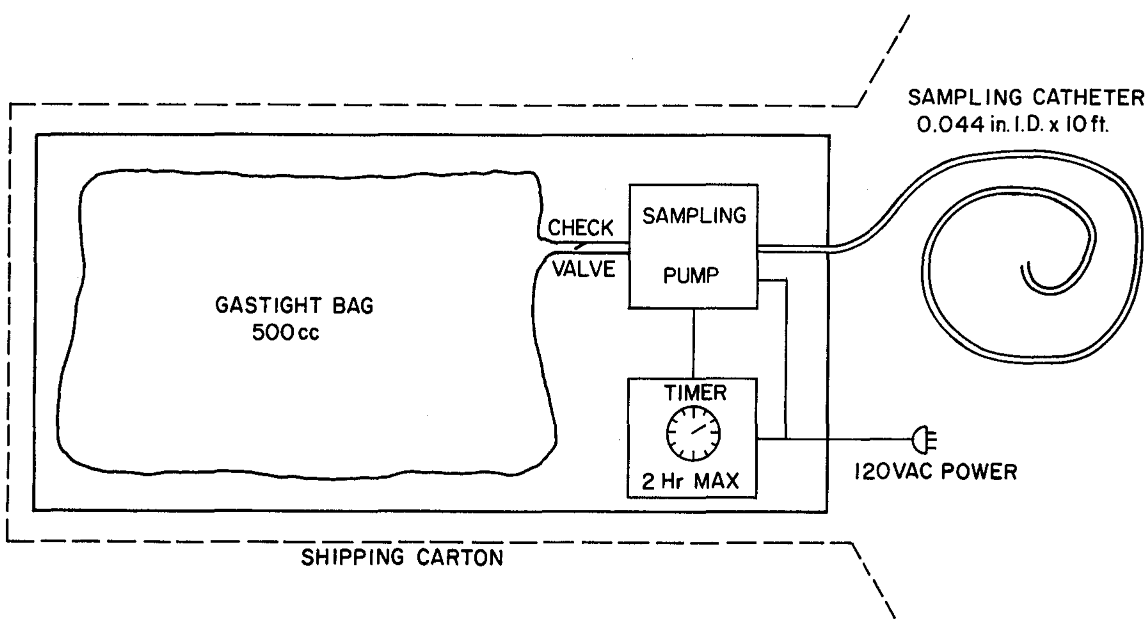

Fig. 15 MAIL ORDER N_2O SAMPLING SYSTEM

The foregoing considerations have led to the development of an air monitoring program based on N_2O sampling when the N_2O flowmeter is on and within the dentist's breathing zone. The recommended program is:

a. At the initiation of the program the suite should be surveyed, with a continuous N_2O analyzer. A less satisfactory alternative is gas analysis by mail order.

b. Samples for analysis are obtained within the breathing zone of the dentist, defined as a frontal area within 6 to 10 inches of his nose. The shoulder is usually a satisfactory sampling site.

c. The sampling pump is turned on when the N_2O flowmeter is turned on and turned off when the N_2O flowmeter is turned off.

d. Total sampling time is to cover at least 1 hour and include several consecutive N_2O procedures. In case such a sample is not achieved within one working day, it is acceptable to monitor fewer cases over a shorter time.

e. Monitoring should be accomplished at the inception of the program and at least every 4 months thereafter.

f. In case a concentration greater than approximately 50 ppm is reported, monitoring is repeated until the cause of the leak is determined. Acceptable concentrations are achieved as rapidly as feasible.

g. Consultation with persons experienced in leak detection and repair should be sought in difficult cases.

The above program is intended to assess the effectiveness of the N_2O control measures. The suggested "reasonably achievable" concentration, as high as approximately 50 ppm, is presented as a working maximum with no intent to discourage the maintenance of lower concentrations.

It could be questioned why the program recommended for the dentist, with sampling only when the N_2O flowmeter is on, should be different from the program which has been recommended for the hospital in which sampling covers the entire workday.[1] The exposure patterns prevailing in the hospital are more constant and lower than in the operatory. When control measures are effective, N_2O levels present in the hospital anesthetist's breathing zone are similar to levels obtained elsewhere in the room, in contrast to the operatory where such similarity was not noted. In the hospital, N_2O levels are easily held to 5-10 ppm and the sharp spikes which are so regularly seen in the operatory are virtually absent. Moreover, the hospital cases are considerably longer. The result is that, in the hospital and regardless of sampling site, a reasonable similarity is seen between time-weighted N_2O concentrations with sampling only when the N_2O flowmeter is on compared to sampling throughout the workday. No such similarity was noted in the operatory.

VII. OTHER METHODS

Additional control measures were evaluated. They are less convenient or less effective than the primary methods which are described above.

A. Air Sweep

The air sweep (Figure 16) assured that the personnel inhaled N_2O concentrations which were only slightly higher than the average prevailing in the room. This technique was employed in offices where air samples obtained in the breathing zones of personnel contained more than 30 ppm N_2O. The apparatus consisted of a quietly operating fan located to take in relatively fresh air

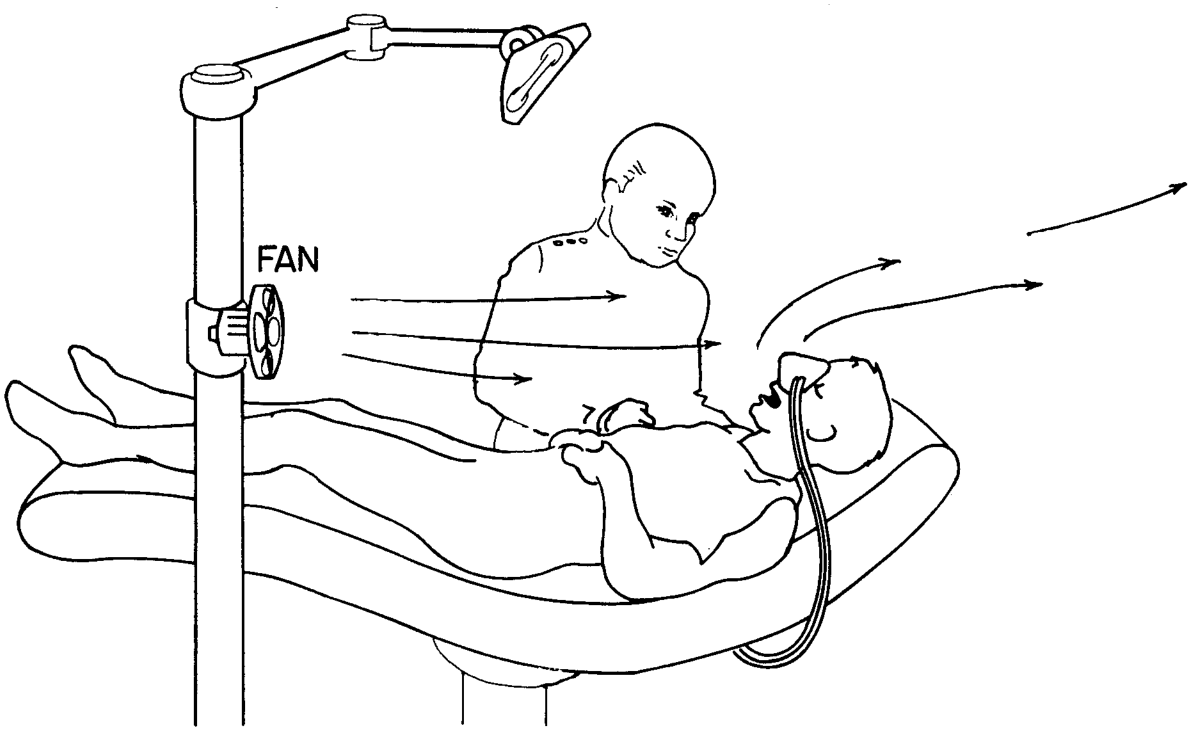

Fig. 16 AIR SWEEP

Fan intake is located away from sources of N_2O. Exhaust is directed to carry concentrated anesthetics, exhaled by the patient, away from the breathing zone of the personnel.

from the treatment room (away from sources of concentrated N_2O). This fresh air is exhausted across the patient's face, thus removing localized high concentrations of N_2O exhaled by the patient from the breathing zones of the personnel. Flow rate was approximately 25 cubic feet per minute at a distance of 3 ft. from the patient's head. This was sufficient to produce a gentle breeze which was acceptable to many patients and dentists.

Results shown in Table 3 indicate that the combination of the scavenging mask with the air sweep fan reduced the dentist's inhaled concentrations obtained with the scavenging mask alone from 31 ± 2.5 ppm to 14 ± 1.5 ppm, a reduction of ~55 percent. A total reduction to 2 percent of the original exposure level was achieved comparing breathing zone samples obtained with the conventional mask with scavenging mask plus air sweep fan.

The air sweep fan was effective in reducing N_2O inhaled by the personnel. However, the other methods described yielded a substantial reduction and are more convenient.

B. Mapleson D Breathing System with a Gas-Tight Mask

A modified Mapleson D (Bain) breathing system (Figure 17), employed with the modified Littell mask*, was employed in a series of 46 oral surgical procedures performed by one dentist. Scavenging was accomplished via a Dupaco relief valve with disposal via suction, employing a pressure equalizing interface.[1] The nosepiece was applied with the headstrap to secure the tightest possible seal,

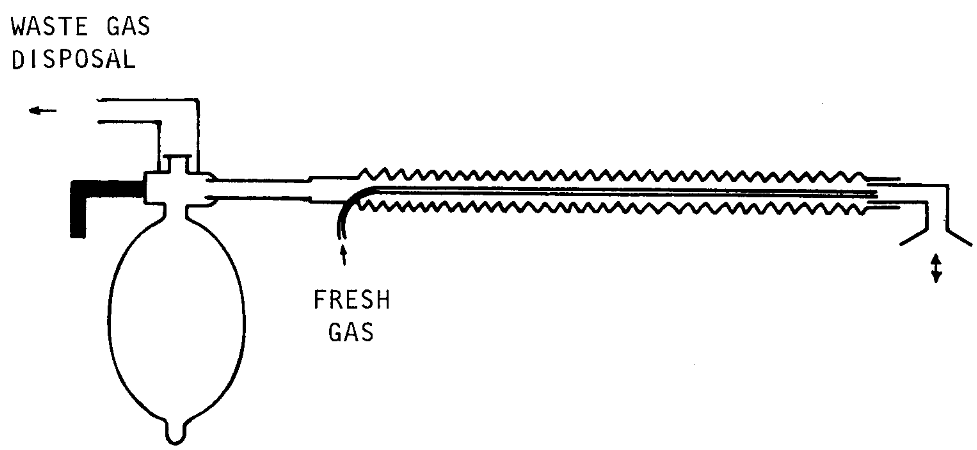

Fig. 17 MAPLESON D (MODIFIED) BREATHING SYSTEM

This is marketed as the Bain Breathing System.

*Mask was modified by sealing its vent.

and the gauze throat pack was fitted with maximum care. Time-weighted breathing zone samples were obtained as in the studies which were conducted in adjacent, working, oral surgical operatories. All equipment was maintained at low-leakage status. Gas analysis was conducted as previously described.

Table 5 compares results obtained with the Littell Mask/ Bain breathing system and the scavenging mask. It is apparent that the oral surgeon inhaled a concentration of N_2O 34 ± 13 ppm with the scavenging mask and 76 ± 8.0 ppm with the Bain system, a difference of -55 percent.

Table 5

PERFORMANCE OF SCAVENGING MASK VS. LITTELL MASK/BAIN BREATHING SYSTEM

CATEGORIES	DAYS OF SAMPLING	NUMBER OF PROCEDURES	SAMPLING TIME (MIN)	N_2O IN BAGS (PPM)
BAIN/LITTELL SYSTEM	16	46	1271	76±8.0
SCAVENGING MASK	9	17	533	34±13
REDUCTION OF N_2O				-55%

± S.E.
SAMPLING WITH N_2O ON ONE DENTIST

The Bain system has been advocated as a scavengeable breathing system suitable for use by the dentist.[20] For efficient operation, it depends on gas-tight seals both at the patient's face and in his oropharynx. Consistent maintenance of such seals is difficult. Back pressure in the scavenging system, present during exhalation, will aggravate any tendency to leakage. The Dupaco relief valve, with its light-weight, non-springloaded disk, and employed in the wide open position, offers minimum resistance. Other relief valves which were evaluated yielded higher breathing zone concentrations of N_2O. On the basis of these comparative studies, the scavenging mask was capable of maintaining the lower concentration of N_2O. The dentist found the Bain/Littell system slightly more convenient to use.

C. Nonrebreathing Mask for Personnel

The use of a nonrebreathing mask supplied with compressed air and worn by the dentist was highly effective, yielding inspired N_2O concentrations less than 1 ppm, but few dentists and assistants would be willing to wear such a mask.

D. Suction Hook and Evacuated Plastic Hood (Figure 18).

A 3 in. length of 1/4 in. I.D. tubing attached to suction was inserted into the patient's mouth in an effort to reduce N_2O leakage. This method, employed as a sole measure, failed to reduce N_2O inspired by the dentist.

An evacuated plastic hood, to cover the patient's nose, nasal mask, and anterior portion of his head, was tried and found to be compatible with use of any conventional mask. Application of the hood, however, was an inconvenience to the oral surgeon and unacceptable to the awake patient.

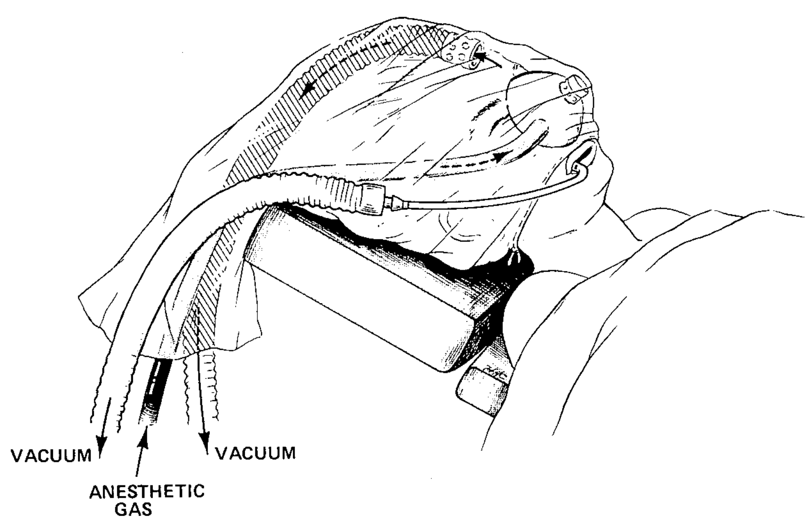

Fig. 18 HOOD WITH SUCTION HOOK

Hood covers patient's head, including nasal mask. Anesthetic gases are removed by slight negative pressure within hood. Mouth hook opens into the patient's mouth where any gases present are removed.

E. Scrubbing the Room Air

Washing the room air could reduce N_2O. Laboratory experiments were conducted with a large, efficient, three-stage industrial scrubber* The objective was to determine whether scrubbing could reduce N_2O present in the exhaust of the air-conditioning system. No significant reduction of N_2O was achieved in the scrubber shown (Figure 19) at a flowrate of N_2O 4 l/min. It was concluded that, although N_2O is highly soluble in water, the process of solution of this gas in water is too slow for effective scrubbing with any unit of manageable proportions. Therefore, this method was not evaluated further.

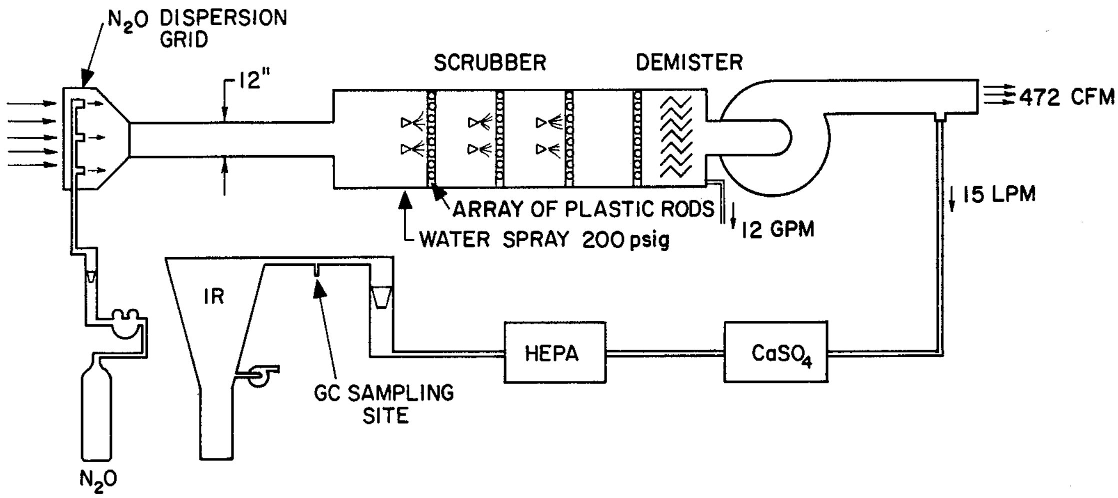

Fig. 19 EXPERIMENTAL SCRUBBER

Efficient removal of N_2O failed to occur under specified condition.

*Krebs Engineers, Menlo Park, California

VIII. ECONOMIC CONSIDERATIONS

Costs of the N_2O control program must be considered. The initial cost for the first year is estimated at $390 per operatory. This figure is based on the purchase of a scavenging mask at $170; installation kit at $30; equipment installation and initial leak testing $100; annual analysis of air samples $90; suction equipment on hand is usually adequate. In subsequent years, the costs for three air samples and 2 hours of technician time for preventive maintenance,would be approximately $140.

The cost of venting a dentist's suction machine outside the building could exceed the allowance included above. However, the need for installing such venting should be infrequent because many suction machines are presently vented in accordance with local building codes.

In consideration of the magnitude of other costs in maintaining the dental suite and in terms of the possible risks of occupational anesthetic exposure, the costs of N_2O control measures seem reasonable.

IX. SUMMARY

In summary, the epidemiological survey studies suggest adverse effects on the health of personnel who work in anesthetizing locations, including the dental operatory. A causal relationship of these effects to chronic occupational exposure to the inhalation anesthetics/analgesics is suspected and is supported by laboratory experiments both in man and in animals. In view of the absence of data to suggest a "safe" environmental concentration of any inhalation anesthetic, below which health hazards are significantly reduced, it is advisable to hold occupational exposure to the lowest reasonably achievable levels.

To achieve optimal control, no single procedure by itself is sufficient, and all sources of leakage must be minimized. The primary procedures begin with servicing the anesthetic equipment to reduce leakage, venting the suction machine to a safe disposal site, and using the scavenging nosepiece. Because unexpected N_2O leakage frequently occurs and escapes detection by the senses, the above procedures must be supported by the air monitoring program. These control measures have held average concentrations of N_2O inhaled by the dentist to approximately 31 ppm.

X. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, in view of the evidence of possible adverse effects on health, and the availability of suitable control measures, a course of action which is prudent and responsible is to make use of the recommended measures. With their employment, the dentist is taking reasonable precautions in protecting his own health, as well as that of his office staff and his spouse.

A. Control measures to reduce N_2O in the breathing zone of the dentist to the lowest reasonably achievable concentrations. Such measures should be consistently employed whenever inhalation analgesia is administered. These include:

1. Use of scavenging equipment,such as the nasal mask described.

2. Venting the suction machine outside the building.

3. Minimizing conversation with the patient.

4. Testing the anesthesia equipment for leakage, high pressure system at least monthly, low pressure system at least weekly when simple test procedures are applicable; otherwise as often as reasonable.

5. Performing preventive maintenance of anesthesia equipment at least semi-annually.

6. Employing the air sweep when acceptable concentrations of N_2O are not achieved with the above measures.

7. Air monitoring program to prove the effectiveness of the control measures. Air monitoring is performed at the inception of the N_2O control program and at least every 4 months thereafter. A reasonably achievable concentration of N_2O appears to be as high as approximately 50 ppm when the recommended control measures are applied and the air is monitored as discussed. In the event that higher concentrations are found, repairs must be promptly completed with verification by a repeat air sample. Samples should be obtained in a frontal area within 6-10 inches of the dentist's nose when the N_2O flowmeter is on.

8. Dentists who administer anesthesia via endotracheal tube should employ those scavenging procedures which are available for hospital anesthesia machines.[1]

B. Dentists to discriminate in their choice of equipment, both for administration of analgesia and for scavenging. Not all equipment offered for sale is equally safe or effective. Procedure-dependent devices are apt to be less effective than devices which are procedure-independent, such as the scavenging mask described.

C. Suppliers of analgesia and scavenging equipment to provide the dentist with documentation, as to patient safety and effectiveness in minimizing N_2O inhaled by personnel.

XI. APPENDICES

A. RELATIVE ROLES OF N_2O AND HALOTHANE IN HEALTH HAZARDS OF THE DENTAL OPERATORY

It is suspected that N_2O contributes to the reported health hazards of the operatory. However, an unknown number of dentists employ halothane* and the possibility that the reported ill-health is due entirely to this agent must be examined. To this end, the expected rates for liver disease and spontaneous abortion in dentists and their wives are calculated for a purposefully overestimated halothane group. These results are compared to the disease rates actually reported.

The authors estimate that halothane is employed in only a very small fraction of anesthetics administered in American dental operatories. For purposes of calculation, this figure has been overestimated at 10 percent. The assumed 10 percent figure is utilized, together with the health histories and the number of dentists regularly employing all inhalation anesthetics, to estimate whether the excess morbidity associated with anesthetic exposure is solely attributable to halothane.

Assuming the use of combinations of halothane with N_2O, and N_2O alone, to include 10 percent and 90 percent of dentists, respectively, and assuming a normal risk for N_2O-exposed dentists, the risk for exposed dentists, p_E, can be expressed as:

$$p_E = .10\ p_H + .90\ p_{N_2O} = .10\ p_H + .90\ p_N$$

where p_E denotes dentists exposed to halothane

p_H denotes percent using halothane

p_{N_2O} denotes percent using nitrous oxide, and

p_N denotes percent normal dentists unexposed to halothane.

Since p_E and p_N can be obtained from the survey[2] for each category, p_H can then be calculated.

The calculation of disease rates becomes:

Predicted Incidence
at 10% Potent Agents

Spontaneous Abortion $$p_H = \frac{16.0 - (.90)\ (9.0)}{.10} = 79\%$$

Liver Disease $$p_H = \frac{5.9 - (.90)\ (2.3)}{.10} = 38\%$$

*The term halothane is used here to denote all potent inhalation anesthetics.

It is apparent that on the basis of the overestimated 10 percent incidence of use of halothane, the calculated spontaneous abortion rate for wives of the exposed dentists becomes 79 percent, assuming the increased rate is solely attributable to halothane with N_2O playing no role. Similarly the calculated incidence of liver disease is 38 percent. These rates are significantly higher than the rates actually reported: i.e., 16 percent and 5.9 percent respectively, and clearly out of range of credibility. It is thus concluded that halothane by itself cannot exclusively cause this health hazard and that N_2O administered as a sole agent must be contributory, if not the principal factor, in explaining the positive findings noted.

B. MANUFACTURERS AND SOURCES FOR N_2O CONTROL EQUIPMENT FOR THE DENTIST*

1. Air Products and Chemicals, Inc., P.O. Box 538 Allentown, Pennsylvania 18105
2. Boehringer Laboratories, P.O. Box 337, Wynnewood, Pennsylvania 19096
3. Calibrated Instruments, 731 Saw Mill River Road, Ardsley, New York 10502
4. Cavitron/KDC Medical Sales, 1528 West Embassy Street, Anaheim, California 92802
5. Ohio Medical Products, P.O. Box 1319, Madison, Wisconsin 53701
6. Spectrex Company, 3594 Haven Road, Redwood City, California 94063
7. McKesson, P.O. Box 188, Moncks Corners, South Carolina 29461
8. Summit Services, 535 Division Street, Campbell, California 95008
9. Wilks, P.O. Box 449, South Norwalk, Connecticut 06856

Key:

Analytical Services	2,8
Scavenging Nasal Mask	7
Gas-Tight Bags	2,3
N_2O Analyzers	1,4,6,9
Air Sampling Systems	2,3,7,8

*Completeness of this list cannot be guaranteed.

XII. REFERENCES

1. Whitcher, C., Piziali, R., Sher, R., and Moffat, R.: Development and evaluation of methods for the elimination of waste anesthetic gases and vapors in hospitals. GPO Stock No. 1733-0071, $2.15, Supt. of Documents, U.S. Government Printing Office, Washington, D.C. 20402, 1975.

2. Cohen, E.N., Brown, B.W., Bruce, D.L., Cascorbi, H.F., Corbett, T.H., Jones, T.W., and Whitcher, C.: A survey of anesthetic health hazards among dentists: Report of an American Society of Anesthesiologists Ad Hoc Committee on the Effect of Trace Anesthetics on the Health of Operating Room Personnel. J Am Dental Assoc 90:1291, 1975.

3. Cohen, E.N., Brown, B.W., Bruce, D.L., Cascorbi, H.F., Corbett, T.H., Jones, T.W., and Whitcher, C.: Occupational disease among operating room personnel: A national study. Report of an Ad Hoc Committee on the Effect of Trace Anesthetic Agents on the Health of Operating Room Personnel. American Society of Anesthesiologists. Anesthesiology 41:321, 1974.

4. Knill-Jones, R.P., Rodriques, L.V., Moir, D.D., and Spence, A.A.: Anesthetic practice and pregnancy. Lancet, 1326, 17 June 1972.

5. Knill-Jones, R.P., Newman, B.J., and Spence, A.A.: Anaesthetic practice and pregnancy. Lancet, 807, 25 October 1975.

6. Fink, B.R., Editor: Toxicity of Anesthetics. Part Four, Teratogenic Effects. Williams & Wilkins Co., Baltimore, p. 259, 1968.

7. Stevens, W.C., Eger, E.I., II., White, A., Halsey, M.J., Munger, W., Gibbons, R.D., Dolan, W., and Shargel, R.: Comparative toxicities of halothane, isoflurane, and diethyl ether at subanesthetic concentrations in laboratory animals. Anesthesiology 42:408, 1975.

8. Chang, W.C., Dudley, A.W., Jr., Lee, Y.K., and Katz, J.: Ultrastructural changes in the nervous system after chronic exposure to halothane. Experimental Neurology 45:209, 1974.

9. Quimby, K.L., Katz, J., and Bowman, R.E.: Behavioral consequences in rats from chronic exposure to 10 ppm halothane during early development. Anesthesia and Analgesia 54:628, 1975.

10. Kripke, B.J., Kelman, A.D., Shah, N.K., Balogh, K., and Handler, A.H.: Testicular reaction to prolonged exposure to nitrous oxide. Anesthesiology 44:104, 1976.

11. Bruce, D.L., Bach, M.J., and Arbit, J.: Trace anesthetic effects on perceptual cognitive and motor skills. Anesthesiology 40:453, 1974.

12. Bruce, D.L. and Bach, M.J.: Laboratory report: Psychological studies of human performance as affected by traces of enflurane and nitrous oxide. Anesthesiology 42:194, 1975.

13. Fink, B.R. and Cullen, B.F.: Anesthetic pollution: What is happening to us? Anesthesiology 45:79, 1976.

14. Smith, G. and Shirley, A.W.: Failure to demonstrate effects of low concentrations of nitrous oxide and halothane on psychomotor performance. Br J Anaesth 48:274, 1976.

15. Jones, T.S., Allen, G.D., Brown, B.W., Greenfield, W., Griffiths, R., Getter, L., Hayden, J., Kerr, I.L., Snead, M.P., Sweptson, B.A., Whitcher, C.E., and Lemke, G.: ADA ad hoc committee issues its report on trace gas hazards. Report of the ADA Ad Hoc Committee on Trace Anesthetics as a Potential Health Hazard in Dentistry. ADA News 8:3, 1977.

16. Criteria for a Recommended Standard -- Occupational Exposure to Waste Anesthetic Gases and Vapors. HEW Publication No. (NIOSH) 77-140. Cincinnati, U.S. Department of Health, Education,and Welfare, Public Health Service Center for Disease Control, National Institute for Occupational Safety and Health, pp. 194, 1977.

17. Millard, R.J. and Corbett, T.H.: Nitrous oxide concentrations in the dental operatory. J Oral Surgery 32:593, 1974.

18. Strunin, L., Strunin, J.M.,and Mallios, C.C.: Atmospheric pollution with halothane during outpatient dental anaesthesia. Br Med J 4:459, 1973.

19. Swenson, R.D.: Scavenging of dental anesthetic gases. J Oral Surgery 34:207, 1976.

20. Allen, G.D., Adams, D., and Scaramella, J.: An inhalation analgesia circuit to minimize nitrous oxide pollution. Anesthesia Progress 23:7, 1976.

21. Piziali, R.L., Whitcher, C., Sher, R., and Moffat, R.J.: Distribution of waste anesthetic gases in the operating room air. Anesthesiology 45:487, 1976.

22. National Fire Codes, Volume 2. Gases 1973-74. National Fire Protection Association, 470 Atlantic Avenue, Boston, Massachusetts 02210. p. 65A-47 (fans); p. 56A-73 (suction) and other sections.

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