Control Of Nitrous Oxide Exposures In Dental Operatories Using Local Exhaust Ventilation: A Pilot Study

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Summary

An experimental portable local exhaust ventilation system was installed in three dental operatories where nitrous oxide was used routinely. Standard methods of exhaust ventilation design used in industry to control exposures to toxic airborne substances were applied to the dental operatory setting. The concentration of nitrous oxide in the dentists' breathing zones was measured before and after installation to determine the efficiency of the system in reducing occupational exposures. Results indicate that placement of the exhaust opening and exhaust air flow rate are important in determining the degree of control achieved. After the system had been installed in one operatory, peak exposures declined from over 600 parts per million (ppm) to less than 70 ppm: the time-weighted average exposure was below the NIOSH recommended level of 25 ppm. A permanently installed local exhaust ventilation system modeled after the portable one used in this pilot study may be feasible for most operatories and should not interfere with dental procedures. The results suggest that nitrous oxide exposures can be greatly reduced if dental operatories are equipped with local exhaust ventilation.

Introduction

Occupational exposure to nitrous oxide has been linked to several health hazards for nearly 20 years.[1] An epidemiological survey of 30,000 dental personnel published in 1980 revealed statistically significant increases in the rate of spontaneous abortion for both wives of male dentists and female dental assistants exposed to nitrous oxide. For female dental assistants working with nitrous oxide, the rates of congenital abnormalities found among offspring and cancer of the cervix were also significantly increased. In addition, elevated rates of kidney, liver, and neurological disease were found.[2]

Animal studies have identified numerous potential health hazards associated with exposure to nitrous oxide, including:

- Adverse reactions of the hematologic system, the cell-mediated immune system, the nervous system, and reduction in the production, motility, chemotactic response, and tumor-killing ability of lymphocytes.[3]
- Depression of bone marrow activity at levels as low as 1,000 ppm[3,4]
- Inhibition of mitosis[5]
- Testicular damage, abnormal giant multinucleated sperm cells and decreased sperm counts,[6] and
- Smaller litter sizes.[7]

Nitrous oxide has been shown to inactivate certain enzyme systems by oxidizing the cobalt in Vitamin B_{12}.[8] This leads to a decrease in serum-methionine levels, reducing the conversion of uridine to thymidine (nucleosides of DNA), which in turn results in a decrease in DNA production. The result is that normal cell division is inhibited. This could help explain some of the reproductive health hazards described above.

In 1977, the National Institute for Occupational Safety and Health (NIOSH) published an extensive review of the toxicity of waste anesthetic gases.[9] The document recommends that exposures to nitrous oxide not exceed 25 ppm (as a time-weighted average for a single procedure.)

Occupational exposures in dentistry have been found to greatly exceed this level. In a recent survey of 27 Georgia dental operatories, the median concentration inside the dentist's breathing zone was found to be 409 ppm. None of the operatories met the level recommended by NIOSH.[10] Another study has

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found peak exposures of 24,000 ppm in operatories not equipped with scavengers.[11]

Recognizing that occupational exposures in dentistry are more difficult to control, another NIOSH study[12] found that time-weighted averages of 50 ppm are feasible. The study recommended that exhaust ventilation, among other measures, be used to control nitrous-oxide levels. Control methods commonly used in hospitals, such as intratracheal intubation, half masks (covering both nose and mouth), and high rates of room-dilution ventilation (15-17 air changes per hour) are not practical in the dental operatory for the following reasons:

- The patient is usually conscious
- The patient's mouth must remain open for most of the procedure, allowing contaminated air to enter the operatory, and
- Normal building ventilation systems are generally not capable of high exchange rates for individual rooms. Of course, separate high volume ventilation systems could be installed in operatories where nitrous oxide is used, although such retrofitting is likely to be expensive.

Scavenging devices have been used in dental operatories with limited success. Only exhalations through the nose can be controlled, and the nose masks commonly used achieve a poor fit, resulting in leakage from gaps between the mask and the patient's face.

In the surveys of Georgia dental operatories, there were indications that scavengers in dentistry are only marginally effective. Only 12 of the 27 operatories were equipped with scavengers; yet exposures in scavenged operatories were not necessarily lower than those in unscavenged operatories.[10] Other variables, including leaks, nitrous oxide flow rate, room dimensions, and building ventilation systems should also be considered in explaining the presence of high N_2O levels in scavenged operatories. None of the operatories surveyed had a local exhaust ventilation system.

We report here the results of a pilot study to evaluate the efficacy of a local exhaust ventilation system as an adjunct to control nitrous oxide exposure. Three operatories, including one without a scavenger, were equipped with a portable local exhaust ventilation system designed according to principles commonly applied to the control of exposures to air contaminants in industry. The results suggest that nitrous oxide exposures can be greatly reduced by using this system.

Methods

Calculation of Required Local Exhaust Ventilation Rates

A capture velocity of 100-200 feet per minute is recommended for contaminants "released at low velocity into moderately still air."[13] The velocity of a patient's exhaled breath measured from approximately 6 inches away was found to peak at about 30-50 feet per minute during normal mouth breathing, a fairly low velocity. Of course, this will vary considerably from one patient to another. If the system is designed for a capture velocity of 200 feet per minute, a distance of 0.5 feet from the exhaust opening to the patient's mouth, and a 5-inch diameter circular opening with a 3-inch flange, the calculated exhaust rate is 396 cubic feet per minute (cfm) (see Appendix for formulae and methods of calculation).

Using the lower range of the recommended capture velocity (100 feet per minute), the calculated exhaust rate is simply half the above rate, or 198 cfm.

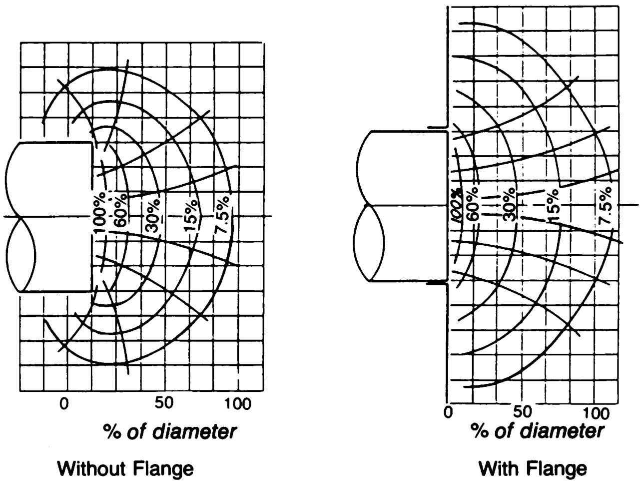
Another study of a local exhaust system in a hospital operating theatre used a lower exhaust rate (about 82 cfm), resulting in average exposures above 50 ppm.[14] This suggests that the higher flow rate calculated above must be strictly observed in order to ensure adequate removal.

The air flow was measured using a multi-point traverse at the face of the exhaust opening in each of the three operatories with an Anderson Air Velocity Meter (a hot wire anemometer). An average air velocity was determined and multiplied by the area of the opening to calculate the total number of cubic feet per minute that was exhausted.

The importance of minimizing the distance between the exhaust opening and the patient's open mouth (or nose mask) can be demonstrated by increasing it from 0.5 feet to 0.75 feet. This increases the required volumetric exhaust flow to 864 cfm. Moving the exhaust opening only three inches further from the patient's mouth results in a 118 percent increase in required exhaust air flow. In short, minimizing this distance is critical to making the most efficient use of any exhaust ventilation system. After consultation with several practicing dentists, it became clear that a distance less than six inches could not be achieved without interfering with the dental procedure.

The importance of using a flanged opening also can be demonstrated by another calculation. For an exhaust opening without a flange, the calculated ventilation rate is 528 cfm. Thus, an additional 132 cfm (33%) would be needed without a flange. The purpose of a flange is to minimize the air pulled from behind the exhaust opening, and thus increase the flow in front of the duct where the nitrous oxide is released into the operatory air (Fig. 1). Normally, a 3-inch flange is recommended for this size opening, but this needs to be weighed against the ease of positioning the opening close to the patient's mouth. The calculations presented above should make it clear that a short distance between the patient's mouth and the exhaust opening is more important than a wide flange (see "Problems" below).

Properly sizing the fan for each operatory based on the static pressure of the entire ventilation system should also be emphasized.



Velocity Contours and Streamlines for Circular Exhaust Openings

Fig. 1 — The effect of a flange on exhaust air flow patterns

Courtesy — American Conference of Governmental Industrial Hygienists

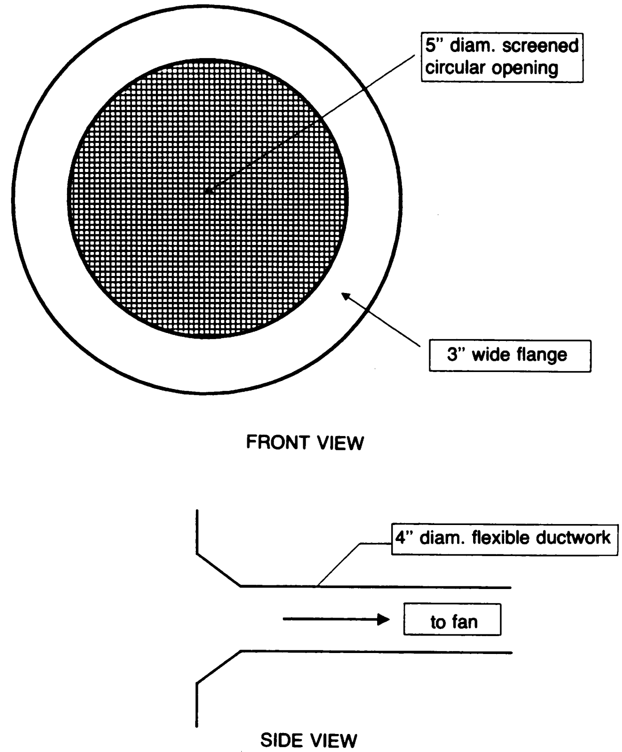


Fig. 2 — Exhaust vent opening

An estimate of the static pressure of a ventilation system is based on the diameter of the duct and the velocity of flow within the duct. For example, the system used in this study had a duct velocity of 2,860 ft/min which was determined by dividing 250 cfm by the cross-sectional area of a 4-inch diameter duct (.0873 ft).[2] The pressure drop is then calculated as 3.72 inches water gauge per hundred feet of straight ductwork (see Appendix). Thus, a fan capable of moving 250 cfm against 3.72 inches static pressure would be required for this system.

The equation given in the Appendix does not apply to flexible ductwork, which will have a greater pressure drop than that given here. It also does not include pressure drops resulting from turns in the ductwork, which need to be calculated individually. Other sources of air turbulence which will contribute to the overall static pressure of the system are losses at both the exhaust opening and the outlet side of the fan. Fan requirements in an exhaust system permanently located in a dental operatory would have to be determined for each individual system, since the size, length, and type of duct, as well as the number of turns, would vary from one system to another.

Design of Exhaust Ventilation System

The exhaust ventilation system was designed to be portable so that it could be temporarily installed in a number of operatories. The system consisted of a 1-horsepower General Electric fan, 25 or 50 feet of 4-inch diameter flexible ductwork, and an exhaust opening mounted on a tripod. The exhaust opening was a tapered 5-inch circular opening equipped with a wire mesh screen to prevent light objects (e.g., paper) from being drawn into the fan, and a 3-inch wide flange (see Fig. 2).

The exhaust vent was initially placed in a number of different locations in the operatories. Smoke tubes were used to help visualize air flow patterns and to ensure that waste nitrous oxide was drawn *away from* (not through) the dentist's breathing zone.

Once the best location for the exhaust opening had been determined, flexible ductwork was attached and directed outside the building. The arrangement for Dentists I and III required 50 feet of duct, while Dentist II required only 25 feet. The duct was connected to the fan, which was placed outdoors away from any fresh air intakes.

Measurements

Measurement of nitrous oxide concentrations was performed using a MIRAN 1A Infrared Gas Analyzer. Calibration of the instrument was accomplished by using a closed loop calibration system before and after each use. A wavelength of 4.5 microns and a pathlength of approximately 7 meters were used. The wavelength was chosen to minimize interference by carbon dioxide, which absorbs infrared light at 4.43 microns.

The sampling port was placed inside the breathing zone of the dentist and/or dental assistant. Measurements were also taken in waiting rooms and receptionist areas before and at the end of the procedures. Only the concentrations measured inside the dentists' breathing zones were used to compute time-weighed averages and develop the graphs presented here.

An initial survey of each operatory was made before the exhaust ventilation system was installed. A follow-up survey was performed after the ventilation system had been installed to determine its effectiveness in reducing occupational exposures to nitrous oxide. For Dentists I and III, these follow-up surveys were performed using different patients on separate days to eliminate interference by nitrous oxide emissions from dental procedures conducted earlier in the day. For Dentist II, the initial and follow-up surveys were performed on the same day, also on different patients. This resulted in some degree of interference from background nitrous oxide levels, which had been generated from earlier use.

Results

The concentrations of nitrous oxide found in each of the three operatories, both with and without the ventilation system in place, are presented graphically in Figures 3, 5 and 6.

Dentist I

Dentist I used a utensil tray placed over the chest of the patient, which made placement of the exhaust opening within 6 inches in front of the patient's mouth impossible using a floor mounted tripod. Instead, the opening was placed 15 inches behind and 6 inches above the patient's mouth, with the dentist and dental assistant seated on opposite sides of the patient. The exhaust flow rate was only 130 cfm, well below the rate of the other two dentists. This was probably caused by the large number of turns in the flexible ductwork, which went up through a false ceiling, out through an opening in the building wall, and down again to the fan outside.

The exhaust rate for the other two dentists was much higher (about 250 cfm). For Dentist II, the ductwork extended in a straight line out through a window. For Dentist III, it went straight down a hallway and out through a rear door. Each turn made by ductwork in any ventilation system increases the air turbulence inside the duct, increasing the static pressure load on the fan.

For Dentist I, the results indicate that although exposures were reduced while the exhaust system was on, there were brief episodes when the nitrous oxide concentration climbed above 600 ppm. Effective control of fugitive nitrous oxide emissions in this case should be considered marginal. The exhaust ventilation system was briefly turned off at point A in Fig. 3 to determine its effectiveness. Levels rose rapidly without the exhaust system on, but declined after it was turned on again.

A scavenger was used in this operatory. Flowrates of nitrous oxide were similar during both the initial and follow-up surveys (2.5 liters/minute).

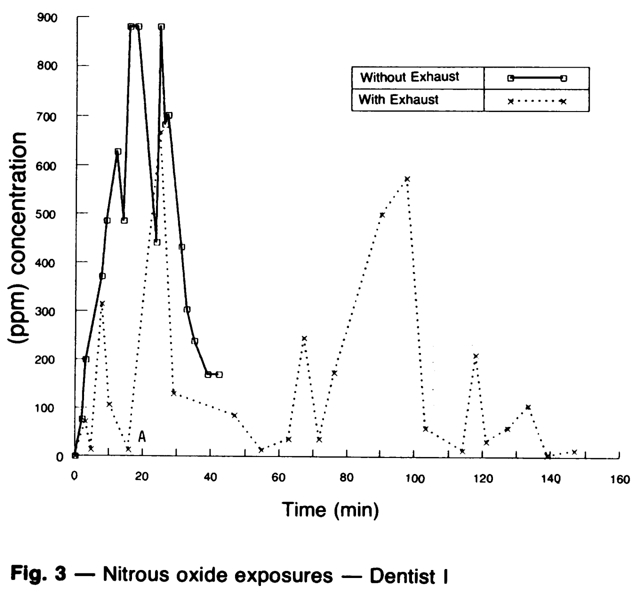


Fig. 3 — Nitrous oxide exposures — Dentist I

Dentist II

Dentist II used a utensil tray positioned behind the patient's head (see Fig. 4), allowing the exhaust opening to be located over the patient's chest about 6 inches from the nose mask using a tripod. In addition, a saliva ejector was held continuously in the patient's mouth for the duration of the procedure. Dentist I had also used a saliva ejector, but placement in the patient's mouth was not continuous. For Dentist II, a concentration of 49 ppm was measured in the operatory and in a hallway near the receptionist area before the exhaust ventilation system was turned on. This background level appeared to be caused by previous procedures when nitrous oxide

Fig. 4 — Local exhaust ventilation for Dentist II

was used. With the exhaust ventilation system on, levels inside the dentist's breathing zone peaked at 68 ppm (see Fig. 5). It is not possible to determine whether this increase was due to variations in background levels (from recirculated air, for example) or from fugitive emissions from the nose mask or open mouth. This emphasizes the importance of evaluating local exhaust capabilities when background concentrations of N_2O are very low, which is usually during the first procedure of the day when nitrous oxide is used. This was done for Dentist III (below).

Use of smoke tubes to visualize air flow patterns also revealed that the operatories of both Dentist II and Dentist III were under a slight negative pressure with the local exhaust system on; levels of nitrous oxide in nearby hallways did not increase during the procedure. In short, a local exhaust ventilation system is likely to confine much of the exposure to those individuals inside the operatory. However, some exposure to office personnel is inevitable, even with the best of exhaust systems, since the patient continues to exhale nitrous oxide while still in the office area. The building ventilation system will also deliver contaminated air to other parts of the office suite, unless each operatory has a separate, dedicated Heating, Ventilation and Air Conditioning (HVAC) system.

Dentist II used a nitrous oxide flow rate of 2.0 liters/minute for both procedures, somewhat lower than the other two dentists. A scavenger was not used in this operatory, suggesting that local exhaust ventilation is more important than scavengers in achieving effective control of waste nitrous oxide in dental operatories.

Dentist III

The most dramatic reductions were found for Dentist III (see Fig. 6). This operatory was fairly small and was equipped with a scavenging device and a utensil

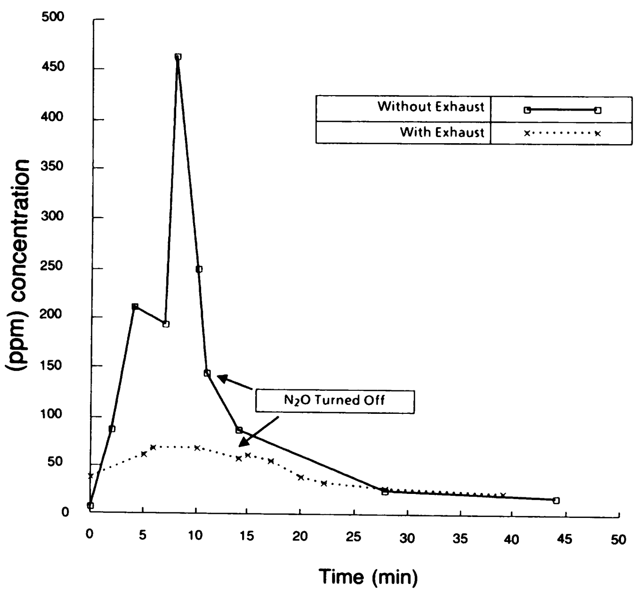


Fig. 5 — Nitrous oxide exposures, Dentist II — no scavenger

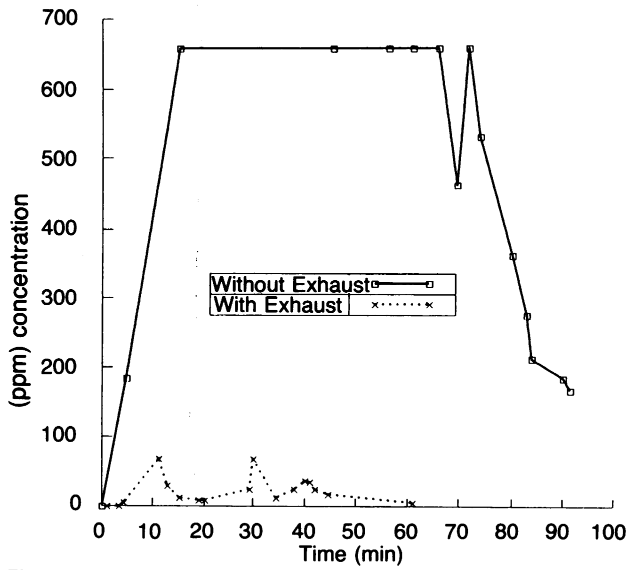


Fig. 6 — Nitrous oxide exposures — Dentist III

tray that could be positioned at the patient's side. The initial survey indicated that exposures were above the highest detection limits for the MIRAN Gas Analyzer (667 ppm) for most of the procedure. However, the follow-up survey found that exposures were much lower with the exhaust ventilation system on.

The nitrous oxide flow rate was set at 3.0-3.5 liters/minute. However, the actual flow rate may have been higher than that indicated, since the ventilation bag remained fully inflated and did not expand and contract with the patient's breathing. This state of high positive pressure may have caused excessive leakage from the nose mask and overcome the scavenging system, thus explaining the high concentrations measured during the initial survey. The bag behaved in a similar manner during the follow-up survey. In the other two dental operatories, the bag expanded and contracted normally.

For the first several minutes of the procedure, levels of nitrous oxide were below detectable levels, indicating that capture of fugitive N_2O emissions was nearly complete. Measurable concentrations of nitrous oxide could only be detected after the exhaust opening was briefly blocked by the dentist's arm as he swung around to the patient's front to administer an injection. Figure 7 pictures the arrangement in this operatory.

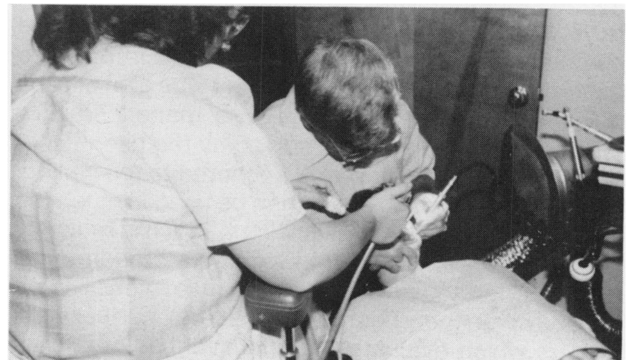


Fig. 7 — Local exhaust ventilation for Dentist III

Time-Weighted Averages

Using the short-term samples obtained from inside the dentists' breathing zones, and assuming that the concentration remained the same until the next reading, the data presented graphically in Figures 3, 4, and 5 can be used to obtain estimates of the time-weighted average for each procedure (Table 1).

TABLE 1. Time Weighted Average (TWA) and Peak Exposures for a Single Procedure (ppm)

	Without Local Exhaust		With Local Exhaust	
	TWA	Peak	TWA	Peak
Dentist I	432	880[2]	170[1]	667[1,2]
Dentist II	239	462	43[3]	68[3]
Dentist III	544	659[2]	21	68

[1]Exhaust off for part of procedure; exhaust opening farther than 6 inches from nose mask.

[2]Highest calibration point of MIRAN Gas Analyzer

[3]Background concentration for this procedure was approximately 50 ppm.

TWA was calculated by the following formula:

$$TWA = \frac{T_i C_i}{\text{Total Time for procedure}}$$

where
TWA = Time-weighted average
T_i = duration of exposure
C_i = concentration of nitrous oxide during T_i

Discussion

Finding a location for the exhaust opening sufficiently close to the patient's mouth to effectively remove nitrous oxide without interfering with the dental procedure posed difficulties in all three operatories. The combined size of the exhaust opening and the flange, together with its lack of maneuverability, tended to make some parts of the dental procedure cumbersome. Since a tripod was used to hold the exhaust opening, proper placement was also difficult due to floor space problems. The maneuverability problems could be largely solved by the use of self-supporting flexible ductwork anchored to the ceiling. The exhaust opening could then be used in much the same way as the examination light, which is routinely positioned for each patient. Such an arrangement is essential for those dentists who use utensil trays located over the chest of the patient. Further field studies which evaluate the effectiveness of such a design are needed.

Comparison of the results for Dentist I and the other two dentists indicate that placement of the exhaust opening and/or the rate of exhaust ventilation (i.e., cfm) are important factors in maximizing the effectiveness of a dental operatory local exhaust ventilation system. In the operatory of Dentist I, there was a greater distance between the exhaust opening and the nose mask, lower exhaust rates, and therefore higher exposures during the follow-up survey than for the other two dentists.

While the operatory used by Dentist II was not equipped with a scavenging device, exposures during the initial survey tended to be somewhat lower than for Dentists I and III, both of whom had scavengers in place. These lower levels may have been caused in part by the larger, more open operatory used by Dentist II. In addition, nitrous oxide was used for a shorter period of time, and was also administered at a slightly lower flow rate. Nevertheless, these results should raise questions about the effectiveness of scavengers in dentistry.

Problems

The dentists involved in the three studies reported the following difficulties in working with this local exhaust ventilation system:

1. The size of the opening was too large to permit clost placement with ease. A 5-inch diameter opening with a 3-inch flange gives a total diameter of 11 inches. Use of a one-inch flange and 4-inch diameter opening would not compromise the system's effectiveness greatly and would reduce the diameter by about half (to 6 inches), increasing ease of maneuverability. A system with ceiling mounted duct work would make routine positioning of the exhaust vent easier. Further studies are needed to evaluate this hypothesis.
2. The noise coming through the exhaust opening from the fan was excessive. Excessive noise can be significantly reduced by use of a quieter centrifugal fan with forward curved blades, together with gradual turns in ductwork to minimize air turbulence. The fan used in this study was not chosen with noise control in mind.
3. All three dentists had questions regarding cost. A rough estimate of the cost of materials for such a system is as follows:

- Pressure blower or centrifugal fan with forward curved blades, capable of moving 250 cfm at 4 inches static pressure - $750
- 20 feet of self-supporting flexible ductwork to be mounted on the ceiling - $50
- 50 feet of 4 inch permanent metal ductwork - $75
- exhaust vent opening with flange - $100

Additional costs would include labor for installation and possibly consultation with a ventilation engineer to properly size the fan. Such consultation would be critical if the length of ductwork is extensive, or if a large number of turns are required. If the dental operatory is located in a large modern office building or a shopping mall, the ductwork is likely to be considerably longer, the fan larger, and the overall system more complicated.

The dentists in this study indicated that a permanently installed exhaust ventilation system modeled after the portable one used here should be considered feasible and would not interfere with the activities of either the assistant or the practicing dentist, if the exhaust opening and ductwork could be suspended from the ceiling.

Potential Sources of Error

- Initial and follow-up surveys were performed while the nitrous oxide was administered to different patients. Different facial characteristics (shape, moustaches, etc.), may have caused poorer nose mask fits on the patients in the initial survey. This could cause more leakage of nitrous oxide from around the nose mask and lead to higher exposures.
- The presence of background levels (due to previous use of nitrous oxide by Dentist II) makes it difficult to determine whether exposures that occurred when the exhaust system was on were the result of the initial procedure, or incomplete capture of fugitive nitrous oxide during the follow-up survey. All future studies need to be done when background levels of nitrous oxide are below detectable levels.
- The time-weighted averages computed in Table 1 are not accurate due to the method of taking short-term samples every few minutes. More accurate measurements of time-weighted averages should be made using a dedicated gas analyzer with the probe placed inside the dentist's breathing zone (preferably attached to the dentist's lapel), with nearly continuous readings analyzed by an integrator. A second gas analyzer should be used to monitor levels at other locations in the dental office suite.
- The time-weighted averages for the initial surveys are likely to underestimate the true exposures for Dentists I and III, since the concentration of some of the short-term samples exceeded the highest calibration point of the instrument.
- Use of only three dental operatories may not give a representative picture of the true feasibility of this control technology.

Conclusions

Use of local exhaust ventilation in dental operatories has the potential for reducing exposures to nitrous oxide below the 25 ppm level recommended by NIOSH. The data presented here suggest that use of this method is effective and feasible, both technically and financially.

Further research is needed to determine the feasibility of installing permanent local exhaust ventilation systems with self-supporting flexible ductwork in existing dental operatories. Such a study should monitor exposures with and without local exhaust ventilation using the same patient, as well as with and without various scavengers, and various gas delivery/scavenging rates. This approach would minimize interference from nitrous oxide released from previous procedures, and would also quantify the effect of each of these variables on nitrous oxide exposure levels.

A three-pronged strategy is needed to control occupational nitrous oxide exposures most effectively, including:

1) Local exhaust ventilation, placed near the patient's mouth;
2) Increased room dilution ventilation, with a dedicated HVAC system for each operatory;
3) Scavengers with effective exhaust (suction) rates.

None of these three measures is likely to be completely effective without the support of the other two.

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Appendix

Ventilation System Design Formulas

The required volumetric flow rates of the exhaust system to obtain a specific capture velocity at a distance from the hood were calculated from the following equations taken from reference 13.

With a flange:
$Q = 0.75\ V\ (10X^2 + A)$

Without a flange:
$Q = V\ (10X^2 + A)$

where
Q = cubic feet per minute (cfm)
V = centerline velocity of air at X distance from the exhaust opening (feet per minute)
X = distance from the exhaust opening to the point of contaminant release (feet)
A = area of the circular exhaust opening (square feet)

Friction loss in ducts was calculated by the following empirically derived formula, also taken from Reference 13.

$$\text{Friction loss/100 feet of ductwork} = \frac{2.74\ (V/1000)^{1.9}}{(D)^{1.22}}$$

where
V = duct velocity (feet per minute)
D = diameter (in inches) of the duct
(This equation applies only to clean, round, galvanized metal ducts, not flexible ductwork.)