

Measurement of scavenged nitrous oxide in the dental operatory

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Abstract

Recent epidemiological studies suggest that chronic exposure to nitrous oxide may be a health hazard to the dental staff and the ADA has recommended that atmospheric nitrous oxide be controlled by use of a scavenging system. These concerns are of special interest to pediatric dentists because studies have shown that the effectiveness of the scavenging system may be influenced by patients' behavior and talking. This study was undertaken to examine the effectiveness of two ADA-approved scavenging systems. The effects of talking and the use of the rubber dam also were examined.

Nitrous oxide levels in the dentist's breathing zone were measured during 80 standardized dental appointments using nitrous oxide-oxygen inhalation sedation. Air samples were collected continuously and analyzed by infrared spectrophotometry. Results showed a significant difference in the effectiveness of the 2 scavenging systems. Neither the rubber dam nor the patient's talking significantly affected levels of scavenged nitrous oxide.

The use of nitrous oxide-oxygen inhalation sedation in dentistry has increased dramatically the past 25 years.¹ Pediatric dentists have found nitrous oxide to be a safe and effective agent in the management of the anxious child patient. Wright and McAuley reported that 44% of pediatric dentists in the American Academy of Pediatric Dentistry used nitrous oxide-oxygen inhalation sedation.² In 1980, a similar survey revealed the number of pediatric dentists using nitrous oxide-oxygen inhalation sedation for behavior management situations had increased to 73%.³

Nitrous oxide was assumed to be safe for both the patient and the dental staff until the late 1960s when epidemiological studies implicated chronic exposure

to trace levels of waste nitrous oxide and other anesthetic gases as a possible health hazard to the dentist and staff. The first report suggesting that chronic exposure to waste anesthetic gases may be a potential health hazard was published in 1967 by Vaisman.⁴ This study encouraged other investigators to examine the relationship between chronic exposure to nitrous oxide and health problems. Human epidemiologic studies consistently have reported increased rates of spontaneous abortion in exposed females and unexposed spouses of exposed males.⁵⁻¹⁰ These studies also have documented significantly increased rates of renal, hepatic, and neurologic disease in exposed individuals as well as congenital abnormalities in their offspring.⁸⁻¹⁰

The ADA has recognized the possibility that exposure to trace amounts of nitrous oxide may present a health hazard to dental personnel¹¹ and has recommended that such trace levels be maintained at the lowest achievable levels by scavenging systems and other reasonable control measures. After reviewing the available literature, the National Institute of Occupational Safety and Health (NIOSH) established a concentration of 50 parts per million (ppm) as a reasonably achievable level of waste nitrous oxide in the dental operatory.¹²

The scavenging system has been examined as a simple and inexpensive means of reducing atmospheric concentrations of nitrous oxide. The literature confirms that scavenging reduces pollutant levels; however, the literature is unclear relative to reductions achievable with scavenging measures. Investigations by 2 independent researchers have found significant differences between commercially available scavenging units.^{13,14} It also has been suggested that such variables as rubber dam use,¹⁴ patient talk-

ing,¹⁵ and patient cooperation¹⁶ may have an effect on the level of waste gas in the operatory. To date, there is little documentation to support these claims.

The purpose of this project was to determine the effectiveness of 2 different scavenging units during nitrous oxide-oxygen inhalation sedation of human volunteer subjects. Two additional variables, rubber dam use and patient talking, also were examined.

Methods and Materials

After Human Subjects Committee approval, 10 adult volunteers ranging in age from 20 to 30 years were selected to participate in the study. Individuals were considered potential subjects if they were at least 18 years of age and in sound health as ascertained from the patient health questionnaire. Potential patients were eliminated if they disclosed health problems requiring special consideration during dental treatment and/or if they felt they might not be able to fully cooperate for a routine operative dental procedure. Signed consent was obtained to proceed with treatment on each individual.

Adult subjects were chosen because the Human Subjects Committee required that the subjects understand and approve all possible risks of such a study. Also, it was important that subjects be totally cooperative in order to control carefully the conditions of the study and manipulate the variables of interest.

General Procedures

Two investigators completed all treatment during a standardized, 15-min dental appointment using nitrous oxide-oxygen inhalation sedation (Table 1). The 3 variables (scavenging mask, talking, rubber dam) were assigned on a random basis (Table 2).

All treatment was performed in a single dental suite

TABLE 1. Standardized Dental Appointment

| Measurement of N ₂ O | N ₂ O Levels | Dental Treatment | Time (min) |
|---------------------------------|-------------------------|----------------------|------------|
| Test for leakage | | | |
| Continuous sampling | 100% O ₂ | Preoxygenation | 3 |
| | 20% N ₂ O | (Talking) | 2 |
| | 80% O ₂ | | |
| | 30% N ₂ O | Rubber Dam | 2 |
| | 70% O ₂ | Placement | |
| | | (Talking) | |
| | 30% N ₂ O | Dental | 5 |
| | 70% O ₂ | Procedures | |
| | | (Talking) | |
| | 100% O ₂ | Postoxygenation | 3 |
| | | (Rubber dam removal) | |
| | | Total Time | 15 |

TABLE 2. Assignment of Variables

| Mask A | Mask B |
|------------|------------|
| Talking | Talking |
| Rubber dam | Rubber dam |
| Talking, | Talking, |
| Rubber dam | Rubber dam |

Each patient was scheduled for 8 appointments and randomly assigned 1 of the 8 variables at each appointment.

in the University of North Carolina School of Dentistry at Chapel Hill. The dental suite was a 2-chair operatory, 1620 ft³ in size. Air was delivered to the operatory through 2 ceiling vents at the rate of 21,600 ft³/hr. For this study, the room air was completely exchanged 13.3 times/hr with a 30% fresh air mix.

Two scavenging systems were used in this study: Mask A — the Brown Scavenging Mask^a; and Mask B — the Fraser Harlake Scavenging Nasal Inhaler^b. Oxygen was delivered to the gas delivery system^c from a wall-mounted central source. Nitrous oxide was delivered from an E-cylinder mounted on the system. The total gas flow for each patient was calculated by the following formula:

$$\text{Total gas flow} = (90 \text{ ml gas}) \times (\text{body weight in kg})$$

The nitrous oxide delivery system was examined for nitrous oxide leakage prior to undertaking this study in the manner suggested by Whitcher et al.¹⁵ The machine also was checked for leakage on a daily basis by passing a sampling catheter connected to the infrared spectrophotometer over the machine and hoses.

Gas Sampling Procedures

Air samples were collected continuously from the dentist's breathing zone by 3 sampling catheters during the 15-min appointment. The breathing zone was defined as being 6-10 in from the nose of the dentist. Catheters were constructed of Tygon[®] tubing and for collection purposes were located at the dentist's mid-clavicle during all sessions. One catheter collected air with a continuous pump^d into a gas-proof bag. This particular sample was analyzed by infrared spectrophotometry and used to generate a time-weighted average (TWA) of nitrous oxide during the sampling period.

The 2 additional catheters collected samples that

^a Summit Services, Inc: Campbell, CA.

^b Fraser Harlake, Inc: Orchard Park, NY.

^c Fraser Harlake Monitored Dial Mixer — Fraser Harlake, Inc: Orchard Park, NY.

^d Mine Safety Appliance portable pump Model G — Mine Safety Appliance Co: Pittsburg, PA.

were analyzed immediately in 2 infrared spectrophotometers.^e One spectrophotometer was calibrated to detect nitrous oxide levels up to 1350 ppm. The second machine was calibrated to measure levels up to 17,600 ppm. The second spectrophotometer was used to verify the reliability of the first spectrophotometer as well as to determine peak values and TWAs in instances where nitrous oxide levels exceeded the limits of the first spectrophotometer.

Both spectrophotometers were calibrated with known concentrations of nitrous oxide by a certified industrial hygienist who operated the equipment during the project. The spectrophotometers were attached to strip recorders to chart continuously the levels of nitrous oxide in the breathing zone of the dentist.

Appointment Procedures

All procedures were performed with the aid of a dental assistant during the 15-min appointment. A second assistant timed procedures and issued instructions to facilitate rigid adherence to the appointment timetable. Each appointment consisted of preoxygenation, nitrous oxide administration, selected dental treatment, and postoxygation (Table 1).

Each volunteer was scheduled for 8 appointments (Table 2). Treatment consisted of placing an occlusal sealant or polishing an existing alloy restoration. A single tooth was treated at each appointment. The tooth was assigned randomly to be isolated with either a rubber dam or cotton rolls. A high-speed evacuation tip was placed in proximity to the tooth during the 5-min dental treatment period and was used regardless of isolation technique. The rubber dam was placed after initiation of 30% nitrous oxide administration and removed during postoxygation (Table 1).

Patients were assigned randomly to talk during appointments. Talking occurred only during nitrous oxide administration. The assistant timing the appointment issued cues to the patient to speak at 30-sec intervals. The patient recited a prepared question after each cue.

Data were analyzed using the Statistical Analysis System (SAS) Program.^f The analysis of variance (ANOVA) was used to test all hypotheses. Alpha levels were set at 0.05 for all statistical tests.

Results

To ensure reliability of measurement, 2 infrared spectrophotometer units were used to measure am-

bient nitrous oxide levels. The correlation between these units was $r = 0.99$ ($p < 0.0001$).

Operator 1 treated 60 patients with a mean TWA of 117.09 ppm (SEM = 25.87). Operator 2 treated 20 patients with a mean TWA of 250.83 ppm (SEM = 106.37). The ANOVA revealed no significant difference between the operators ($F = 2.57$, $p < 0.05$). There were no significant interactions between operators and other variables of interest.

Values obtained for each scavenging mask are listed in Table 3. The mean TWA for 40 appointments using Mask A was 80.34 ppm nitrous oxide. The median TWA was 56.15 ppm and 18 appointments were below the NIOSH standard of 50 ppm. The mean TWA for appointments using Mask B was 220.72 ppm. The median TWA was 92.89 ppm and 7 appointments were below the NIOSH standard.

The difference between Mask A and B was statistically significant at the 0.05 level (Table 4). There were no statistically significant interactions with any other variables.

Values obtained for appointments by isolation technique are listed in Table 3. The mean TWA for 40 appointments using rubber dam isolation was 108.65 ppm. The mean TWA for 40 appointments using cotton roll isolation was 192.41 ppm. This difference was not statistically significant (Table 4). There were no statistically significant interactions with any other variables.

Values obtained for appointments for talking are listed in Table 3. The mean TWA for 40 appointments in which the patient was asked to talk was 144.35 ppm. The mean TWA for 40 appointments in which the patient did not talk was 156.71 ppm nitrous oxide. This difference was not statistically significant (Table 4). There were no statistically significant interactions with any other variables.

There was a positive correlation ($r = .44$) between TWA and peak value. This correlation was highly significant ($p < .0001$).

Discussion

The diverse results in previous studies of trace levels of nitrous oxide in the dental operator may be explained in part by differences in research designs, methodological techniques, and selection of values for consideration and reporting. However, it is likely that the most significant reason for disagreement over the effectiveness of scavenging in the dental operator is the scavenging system itself. Although there have been references in the literature concerning the performance of the 2 masks, this is the first study to measure systematically levels of nitrous oxide in a controlled situation and report a significant difference in performance between Mask A and B. Previously,

^e Miran #1A — Wilks: South Norwalk, CT.

^f SAS Institute, Inc: Cary, NC.

TABLE 3. Comparison of Nitrous Oxide Levels (TWA) from Present Investigation

| | Mean | SEM | Range |
|---------|--------|-------|---------------|
| Mask A | 80.34 | 13.54 | 8.13–414.47 |
| Mask B | 220.72 | 63.82 | 13.13–2264.18 |
| Dam | 108.65 | 16.88 | 14.64–535.62 |
| No dam | 192.41 | 64.26 | 8.13–2264.18 |
| Talk | 144.35 | 54.88 | 8.13–2264.18 |
| No talk | 156.71 | 38.58 | 18.48–1111.98 |

N = 40 for all groups.

Values are reported in parts per million (ppm) nitrous oxide.

TABLE 4. Evaluation of Performance

| Source | DF | SS | F Value | P Value |
|---------------|----|------------|---------|---------|
| Model | 16 | 1383147.23 | 0.940 | 0.53 |
| Error | 63 | 5821195.38 | | |
| Total | 79 | 7204342.61 | | |
| Subject | 9 | 693855.96 | 0.083 | 0.59 |
| Mask | 1 | 394123.87 | 4.270 | 0.04* |
| Dam | 1 | 140346.15 | 1.520 | 0.22 |
| Talk | 1 | 3058.01 | 0.003 | 0.86 |
| Mask-dam | 1 | 131400.77 | 1.420 | 0.24 |
| Mask-talk | 1 | 205.45 | 0.000 | 0.96 |
| Dam-talk | 1 | 16863.15 | 0.180 | 0.67 |
| Mask-dam-talk | 1 | 3293.87 | 0.040 | 0.85 |

* Significant at the $\alpha = 0.05$ level. DF = degrees of freedom. SS = sum of squares.

Mask A had been found to reduce waste nitrous oxide gas to acceptable levels by NIOSH standards in studies by Tonn and Whitcher,¹ Hallonsten,¹³ and Whitcher et al.¹⁵ In this investigation the TWA of Mask A was similar to TWAs in studies exceeding recommended limits. While Hallonsten¹³ has reported that Mask B achieved a TWA below the NIOSH directive using a gas delivery system different from the one employed in this project, most studies have found unacceptable levels using Mask B.^{13,14,16} Although the effect of different gas delivery systems on nitrous oxide levels has not been investigated directly, there are indications that levels may vary depending on the system used.^{13,14}

The levels of ambient nitrous oxide monitored during experimental or controlled dental situations must be reviewed carefully before making comparisons with values obtained during actual dental practice. It is reasonable to assume that occupational exposure to nitrous oxide may vary according to the length and nature of the procedure undertaken in the given appointment. Badger and Robertson have commented

on the possible effects of behavior.¹⁶ Additionally, Campbell et al. have suggested that the difficulty of the procedure may influence the amount of exposure the dentist receives.¹⁷

Operatory size and room ventilation may affect the amount of ambient nitrous oxide that accumulates during nitrous oxide sedation. However, Whitcher et al. felt that air conditioning systems play a minor role in the concentration of nitrous oxide inhaled by the dental personnel.¹⁵ In this investigation the number of room air changes per hour and the percentage of fresh air mixed in with recirculating air was set at the maximum limit of the ventilation system. This was done because it was found that room air concentrations of nitrous oxide dramatically decreased as the number of room air changes and percentage of fresh air increased. In theory, the size of the operatory should not have an effect on ambient nitrous oxide, given an equal number of room air changes and the same percentage fresh air mix. However, this has not been investigated systematically because the important question relates to levels in the dentist's and as-

sistant's breathing zones. There is overwhelming evidence that these zones have the highest levels of nitrous oxide at all times.¹⁵

The literature suggests that conversation by the patient is a major source of nitrous oxide pollution in the operatory. However, this has not been documented in clinical research and the findings in this study show absolutely no elevation of ambient nitrous oxide associated with talking. The finding here might be explained by the fact that appointment length may have been too short for nitrous oxide levels to build up, or perhaps the questions repeated by the patient were not an accurate representation of talking in the operatory. A plausible explanation may be that the high-speed saliva evacuator tip was near the mouth during the restorative procedures and this may have acted as a secondary or back-up scavenging unit. Further investigation into the effects of talking and the influence of the saliva evacuation system are warranted.

The use of rubber dam isolation had no significant effect on nitrous levels in the operatory. Almquist and Young have stated that significant reductions (30%) in atmospheric pollution result when rubber dam isolation is utilized.¹⁴ The high-speed evacuation system may work similar to a local exhaust system recently developed as another means of reducing nitrous oxide in the operatory.^{18,19}

Based on findings in this study, the correlation between TWA and maximum peak value may be substituted as a crude measure of occupational exposure. Although sophisticated monitoring equipment still would be required, this would free the dentist and assistant from having to wear the pump and bag apparatus during dental procedures. The new passive diffusion dosimeters will record a cumulative exposure to nitrous oxide, but will not pinpoint leaks in the equipment or procedures that result in excessive amounts of ambient nitrous oxide.

The significant difference between scavenging masks needs further investigation. Because both masks operate on similar scavenging principles, it is reasonable to expect that they should scavenge with equal efficiency. Yet, Mask A reduced mean waste nitrous oxide levels to significantly lower levels than Mask B and also performed more consistently. Several appointments using Mask B recorded ambient nitrous oxide levels well above 1000 ppm. The presence of outlying values suggested that median values might be a more meaningful and accurate measure of scavenging efficiency. However, the difference between masks existed for median values as well.

The results of this study reveal that neither mask achieved a mean TWA value below the 50 ppm standard set by NIOSH. TWA values were below the NIOSH standard in only 25 (31%) of the 80 appoint-

ments. The percentage of appointments meeting NIOSH requirements was 45% for Mask A and 18% for Mask B. Despite the fact that a majority of the appointments did not meet NIOSH requirements, the values obtained in this project should be thought of as minimum values of occupational exposure. This claim is supported by a review of precautions undertaken during this study to minimize ambient nitrous oxide levels during experimental procedures. These include:

1. The equipment was selected from the list of acceptable or provisionally acceptable products as determined by the ADA Council on Dental Materials, Instruments, and Equipment. Furthermore, all equipment was examined daily during the study for nitrous oxide leakage.
2. The room ventilation in the operatory was adjusted to provide the maximum amount of fresh air mix and the greatest number of room air changes per hour by the air conditioning system serving the operatory.
3. Standard inhalation analgesia protocol was followed.²⁰ The mask was adjusted during preoxygenation to fit the patient as well as possible because a well-fitting mask has been reported to reduce occupational exposure.^{13-15,17,19,21} Also, nitrous oxide accumulated in the body during the procedure was scavenged as it was released from the lungs during the postoxygation period.
4. High-speed evacuation was used to scavenge gas according to the manufacturer's instruction. Waste gas was exhausted from the roof top as suggested by the Council on Dental Materials, Instruments, and Equipment. Because it has been reported that nitrous oxide levels decrease when the saliva evacuation tip is held in the mouth,¹⁹ high-speed saliva evacuation was practiced regardless of isolation technique.
5. Lack of cooperation has been identified with increased levels of nitrous oxide.¹⁶ In this study, the volunteer patients were cooperative and followed instructions as directed; furthermore, they breathed only through the nasal mask and did not talk unless requested to do so. Numerous authors have recommended that patients refrain from speaking in order to control atmospheric nitrous oxide levels.^{1,13,15,19}
6. The standard dental appointments were 15 min in length and nitrous oxide was administered for only 9 of the 15 min. Dental procedures generally exceed this length of time and may last much longer. The scientific literature confirms that ambient nitrous oxide levels increase with the duration of the procedure.^{22,23}

In summary, there is compelling evidence to sup-

port the fact that the levels achieved in this controlled study are much lower than might be expected in the routine dental operatory setting.

Conclusions

This study was undertaken to compare the effectiveness of 2 scavenging units during nitrous oxide-oxygen inhalation sedation. Two additional variables, rubber dam use and patient talking, also were examined. The TWA of 80 patient appointments were measured. The data supported the following conclusions:

1. There was a significant difference in the effectiveness of the 2 scavenging masks in reducing ambient levels of nitrous oxide in the dental operatory.
2. There was no significant difference in the levels of ambient nitrous oxide whether or not a rubber dam was placed in the mouth.
3. There was no significant difference in the levels of ambient nitrous oxide whether or not the patient talked.
4. There was a significant correlation between the TWA nitrous oxide level for a given appointment and the peak (maximum value) for that same appointment.

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