

Clinical evaluation of the efficacy of three nitrous oxide scavenging units during dental treatment

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There are environmental health concerns for dental health care providers chronically exposed to trace amounts of waste nitrous oxide (N_2O). This study compared the effectiveness of three N_2O scavenging systems, the Porter/Brown, the Accutron, and the Matrx, in actual time during use in a standardized mock dental treatment protocol that reflected clinical practice while minimizing the influence of confounding variables. At every occasion during the procedure, the Porter/Brown scavenger system left the operator with significantly less N_2O than any of the other scavengers tested. The Porter/Brown removed between 71% and 91% of the N_2O compared to the control (no device).

Received: September 21, 2001

Accepted: October 29, 2001

Introduced as an anesthetic in 1844, the analgesic, anxiolytic, and psychosedative properties of nitrous oxide (N_2O) make it a nearly ideal agent for use in outpatient sedation for dental procedures. The ADA Council on Scientific Affairs and the ADA Council on Dental Practice have stated that "nitrous oxide continues to be a valuable agent for the control of pain and anxiety."¹ However, there are environmental health concerns for dental health care providers chronically exposed to trace amounts of waste N_2O . Chronic N_2O exposure has been linked to spontaneous abortion and reduced fertility, irritability, headache, nausea, congenital abnormalities, lymphoid malignancies, cervical cancer, and hepatic, renal, and neurological disease.²⁻⁴

Bruce and Bach investigated the effects of N_2O exposure on operator performance.^{5,7} They observed decreased psychomotor performance in visual perception, immediate memory, and cognitive and motor responses in human subjects receiving as little as 50 ppm N_2O over a two hour period.⁸ Subjects exposed to 25 ppm N_2O did not demonstrate such effects. In a similar study, Cook found no changes in performance until the subjects were exposed to 20% N_2O , or the equivalent of 200,000 ppm.⁹

The literature reveals a lack of agreement concerning safe limits for the ambient level of N_2O . The National Institute of Occupational Safety and Health

(NIOSH) recommends a maximum allowable time weighted average (TWA) of 25 ppm of total N_2O exposure in both the operating room and the outpatient setting.⁴ It was determined that 25 ppm was achievable in the operating room but not attainable in the dental operator. Therefore, NIOSH chose 50 ppm to be the maximum exposure limit for personnel in the dental setting.¹⁰ The American Conference of Governmental Industrial Hygienists recommends a N_2O exposure limit of 50 ppm for an eight hour TWA.¹⁰ Among the methods used to control N_2O exposure in the dental office, the ADA emphasizes the routine use of scavenging equipment.^{1,11} Levels of ambient N_2O have been reported to be 300–1,000 ppm when scavenging units are not used.¹² Further, studies have shown that some scavenging systems do not consistently maintain the operator's breathing space to within safety standards.^{13,14}

Few studies have compared the effectiveness of different N_2O scavenging systems.¹⁷ A number of variables related to the delivery of N_2O sedation are difficult to control and complicate such studies. These include the type of dental procedure, mouth breathing, patient movement, mask fit, and quality of high-speed evacuation.²⁰⁻²³ Previous studies have found the Porter/Brown N_2O scavenging system to be superior to others.¹⁵⁻¹⁹ Donaldson reported that the mean ambient N_2O level following use of the Porter/Brown device during a dental procedure

was 43.4 ppm.¹⁸ These studies, however, involved the collection of gases throughout the dental procedure and a TWA of the N_2O at a specific time, not the actual time of exposure to N_2O by the dental team.

The ADA has published recommendations for controlling N_2O exposure.¹ The report stated that dental offices could control N_2O exposure by implementing current recommendations on scavenging equipment maintenance and work practices. However, the level of N_2O in dental offices that follow these recommendations has not been established. This study sought to compare the effectiveness of three N_2O scavenging systems in actual time during their use in a standardized mock dental treatment protocol that reflected clinical practice while minimizing the influence of confounding variables. The hypothesis is that there is no difference in ambient N_2O measurements between the three scavenger units during mock dental treatment.

Materials and methods

Three N_2O scavenging devices were tested following a controlled clinical protocol. The scavenging devices differ in mask design. The Accutron Model No. 32203 Alpha MX (Accutron, Inc., Phoenix, AZ; 800/531-2221) and Matrx MDM (MDS Matrx, Orchard Park, NY; 800/847-1000) have one rubber nasal hood with a small plastic scavenging cap perched at the top of it (Fig. 1). The Accutron is disposable after one usage; the Matrx can be autoclaved. The Porter/Brown Model No. 2445-1 (Porter Instrument Company, Inc., Hatfield, PA; 800/457-2001) incorporates two rubber pieces into the mask design and can be autoclaved (Fig. 1). The scavenging units are similar in that the mask is connected to a high evacuation tubing that evacuates ambient N_2O and exhaled air at 45 L/minute out of the building.

The study population consisted of 12 volunteers, 7 men and 5 women, who

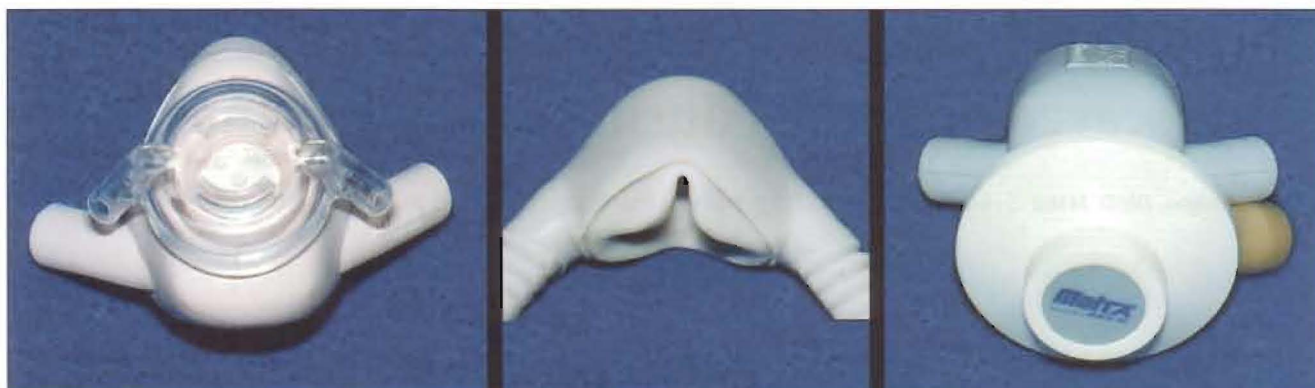


Fig. 1. N₂O scavenging units: Accutron, Porter/Brown, Matrix.

ranged in age from 22–44 (mean = 25 ± 3.5). The subjects were selected at random from a population of dental school volunteers. All subjects met the criteria for Class I of the American Society of Anesthesiology. None used tobacco products; none of the female subjects were pregnant.

The subjects participated in four clinical sessions at one-week intervals. During these sessions, each volunteer was exposed to either one of the three N₂O scavenger units or to a control that used no scavenger unit. The order of exposure to each of the variables was determined by a randomized computer-generated schedule established by an investigator not associated with the clinical portion of the study. Informed consent was obtained prior to subject participation in this investigation. A pilot study was performed to minimize variation between subjects, calibrate the instruments and the procedures, and expedite reproducibility.

Operatory preparation

All testing was conducted in the same ventilated operatory with an air flow rate that produced six air exchanges per hour. The N₂O delivery machine was evaluated for proper connections and protection against gas leakage immediately before each experimental session, in accordance with ADA-recommended protocol.^{1,11,24-26} Prior to each session, room air was evaluated using an infrared spectrophotometer to determine the baseline value of N₂O in the operatory.

Patient preparation and clinical monitors

Before each clinical session, each patient was given oral and written instructions including pretreatment and posttreatment dietary restrictions, activity limitations fol-



Fig. 2. Adjusted N₂O scavenger hood.

lowing the study, and a 24-hour contact telephone number. On the day of the study, the subject was seated in a standard dental operator chair. Inhalation mask application and nose breathing technique were explained to each patient. The patient was encouraged to remain still and to minimize talking and mouth breathing. The room ambient temperature was recorded. Patient blood pressure (BP), pulse, and blood oxygen saturation were recorded electronically by the Passport XG (Datascope Corp., Montvale, NJ; 800/288-2121). The patient's respiratory rate was recorded to establish baseline measurements.

The door to the operatory was closed, the patient was placed in a semi-supine position, and a nasal hood was applied. Oxygen was delivered at a rate of 9.0 L/min. The hood was adjusted for both fit and comfort (Fig. 2). The patient was asked to relax and reminded again to breathe only through the nose. Respiratory rates were recorded again at minutes 3 and 12 of the procedure. A pulse oximeter was used to continually monitor the patient's oxygen saturation; readings were taken at 3, 12, and 16 minutes.

N₂O titration

As soon as the patient reported being comfortable with the position of his or her body



Fig. 3. "Dummy" bur used during mock dental treatment.

and the position of the nasal hood, the investigator began titration of N₂O. A constant gas volume technique was used. N₂O was adjusted to a 1.0 L/min flow while oxygen flow was reduced to 8.0 L/min. The patient breathed this 11% N₂O mixture for three minutes. If there were no untoward events and the patient still was comfortable, the flow of N₂O was increased to 2.0 L/min and the oxygen flow was reduced to 7.0 L/min (22% N₂O). The patient breathed this new mixture for six minutes, at which time a rubber dam was applied to isolate the maxillary anterior teeth. The dam was held away from the patient's face using a Young's frame. The N₂O flow was increased to 3.0 L/min with a concomitant oxygen flow rate of 6.0 L/min (33% N₂O). This final N₂O/O₂ ratio was maintained for nine minutes, during which a sham operative dental procedure was conducted. At the completion of this sham treatment, the N₂O was secured and the oxygen flow was increased to 9.0 L/min for at least four minutes to purge the N₂O from the patient. The total length of exposure to N₂O per subject was 18 minutes.

Table 1. Comparing the baseline vital sign values of the four groups.

Group	Systolic BP			Diastolic BP			Respiration rate			Pulse rate			Room air N ₂ O		
	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
Control	12	114.8	7.21	12	64.9	3.82	12	12.25	1.357	12	69.8	11.53	12	3.25	2.56
Accutron	12	117.6	13.43	12	69.8	10.83	12	13.00	1.758	12	72.7	11.56	12	3.25	2.22
Matrx	12	118.4	10.78	12	67.8	8.62	12	13.92	2.392	12	73.0	17.63	12	3.38	1.25
Porter/Brown	12	114.3	10.40	12	64.7	6.37	12	12.75	1.215	12	66.8	11.34	12	2.50	1.68
All	48	116.3	10.69	48	66.8	7.86	48	12.98	1.741	48	70.6	13.29	48	3.09	1.99



Fig. 4. Miran 203 sensor adjusted 18 inches from patient's head at the two-o'clock position.

In all cases, patients were alert and responsive throughout the treatment period. The patients were able to independently maintain a patent airway and respond appropriately to physical stimulation and verbal commands at all times. The concentrations, flow rate, and duration of administration of oxygen and N₂O were documented. No patients experienced any discomfort at any time during the procedure. No treatment was aborted due to an untoward reaction.

Sham procedure

The sham dental operation simulated tooth cavity preparation (Fig. 3). A "dummy" bur was used in a high-speed handpiece. The "dummy" bur is incapable of cutting action and serves only to

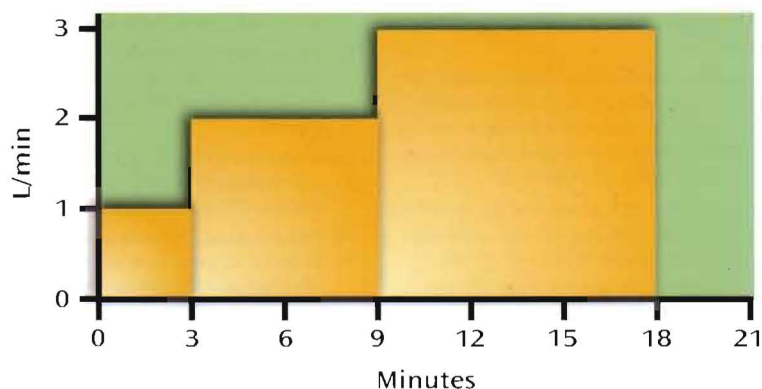


Fig. 5. Graph of ambient N₂O (ppm) level plotted over time for each of the three N₂O scavenger units and the control.

stabilize the handpiece bur chuck during operation. The handpiece ran for one minute in the subject's mouth at full speed with a standardized flow of coolant/irrigation water. An assistant applied high-speed evacuation at the same time. After a 15 second break, the handpiece was run again for another minute, followed by another 15 second break and a final one minute run. Following the completion of handpiece operation, the patient continued to breathe the gas mixture until it was secured.

Documentation and clinical measurements

A portable infrared spectrophotometer sensor (Miran 203, Invensys, Foxboro, MA; 866/746-6477) was calibrated professionally prior to the study. The instrument's sensor was placed opposite the dentist at a height of 18 inches above the patient's nose at the two o'clock position (Fig. 4). The sensor position simulated that of a dentist or technician on the other side of the dental chair. This position has been used previously and was chosen

to minimize interference with spectrophotometer accuracy due to carbon dioxide and water vapor exhaled by the investigator. The spectrophotometer was calibrated using a N₂O filter before each clinical trial. Ambient N₂O concentrations, registered by the spectrophotometer, were recorded at baseline, 3, 9, 10, 13, and 18 minutes and after 4 minutes of 100% oxygen (Fig. 5). The recorder remained blinded during the entire course of the clinical trials.

Clinical control

All volunteers participated in a clinical control session in which the study design was duplicated with one exception: no scavenging system was employed. During these sessions, the researchers breathed through portable oxygen units.

Results

Baseline differences

The first analysis compared the baseline values of the four groups. Summary descriptive statistics are shown in Table 1. The four groups did not have a different

diastolic BP ($F(3, 44) < 1, p = 0.7298$), systolic BP ($F(3, 44) = 1.2, p = 0.3243$), respiration rate ($F(3, 44) = 1.9, p = 0.1385$), pulse rate ($F(3, 44) < 1, p = 0.6428$), or room air N_2O ($F(3, 44) < 1, p = 0.6948$).

Ambient N_2O levels (ppm) were analyzed using the repeated-measures cross-over approach of Jones and Kenward to compare the scavengers across time.²⁷ The analysis uses the baseline as a covariate (the baseline N_2O values were taken to be the average of the room air level and the zero-minute level) and uses subjects as their own control. The model also included effects for scavenger, minutes, a scavenger·minutes interaction, and period, meaning that the N_2O values at 3, 9, 10, 13, 18, and 22 minutes were compared using the baseline as a covariate. The subjects were tested during four experimental periods. A cross-over design also must assess whether there is any significant difference associated with the first through the fourth observation period; there was not for this study ($F(3, 249) = 1.11, p = 0.3470$).

The means for each group at each data collection time are shown in Table 2 and illustrated in Figure 5. The N_2O flow rate is shown in Figure 6. As the N_2O flow rate increased, the ambient N_2O level also increased until after 10 minutes. There was a significant increase in N_2O levels between 3 and 9 minutes overall, between 9 and 10 minutes overall, and within each scavenger ($p < 0.0001$) for both intervals. The decrease in ambient N_2O at the 13 minute measurement can be explained by the high volume evacuation used during the sham operation. There was a significant decrease in N_2O levels between 10 and 13 minutes overall and also within each scavenger ($p < 0.0001$); a significant increase in N_2O levels between 13 and 18 minutes overall and also within each scavenger ($p < 0.0001$); and a significant decrease in N_2O levels between 18 and 22 minutes overall and also within each scavenger ($p < 0.0001$).

The repeated-measures ANOVA results for the interaction between scavenger·time indicated that the differences between the four scavenger conditions were not constant at each time point ($F(15, 249) = 178, p < 0.0001$). Therefore, the four scavenger conditions were compared at each time point. Each of the scavenger groups differed significantly from the others. The Porter/Brown unit

Table 2. Mean N_2O values (ppm).

Time (in minutes)	Control	Accutron	Matrx	Porter/Brown
0	3.25	2.83	3.38	2.50
3	47.17	22.83	36.67	9.50
9	85.42	39.58	69.92	19.58
10	93.50	49.00	82.25	27.00
13	86.58	29.17	46.08	12.33
18	98.08	65.50	82.08	34.08
22	97.00	20.08	33.25	9.17

Table 3. Mean blood oxygen saturation (percentage).

Time (in minutes)	Control	Accutron	Matrx	Porter/Brown
3	98.75	99.17	99.50	99.42
12	98.83	99.25	99.25	99.08
16	98.92	99.00	99.42	99.00

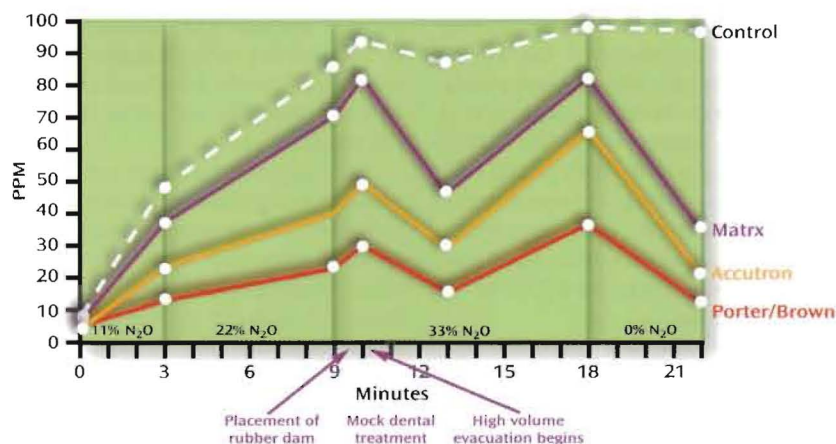


Fig. 6. Graph illustrating that as the N_2O flow increases, the ambient N_2O level also increases.

was the most efficient, followed by the Accutron and the Matrx. At every time interval during the procedure, the Porter/Brown scavenger left the operator with significantly less N_2O than any of the other methods. The Porter/Brown scavenger removed between 71 and 91% of the N_2O compared to the control.

Oxygen was assessed at three time points during the procedures. The means are shown in Table 3. Blood oxygen saturation was analyzed with repeated-measures ANOVA. There was no significant interaction between the four scavenger methods ($F(4, 44) = 1.36, p = 0.2683$), no

significant change across time ($F(2, 88) = 1.59, p = 0.2090$), and no significant interaction between group and time ($F(6, 88) = 2.07, p = 0.0644$). The average blood oxygen saturation value (expressed as a percentage) using any these four methods was 99.1% (SE = 0.37%).

Discussion

The significant finding of this study was that at all times during the clinical trials, N_2O levels were significantly lower using the Porter/Brown scavenger than either the Matrx or Accutron devices during mock dental treatment. The Porter/

Brown scavenger removed between 71% and 91% of the N_2O compared to the control. The Porter/Brown maintained ambient N_2O levels below 50 ppm; the other units did not. This study confirms the results of previous studies indicating that the Porter/Brown scavenger performed better than the other two scavenging systems.¹⁵⁻¹⁹ These findings are of significance to dental health care providers.

A distinct advantage of the Porter/Brown mask design is that a tight fit is not critical. The outer mask design is open, permitting effective evacuation of the escaping gas to occur around a loosely fitted nosepiece.¹⁸ The Porter/Brown outer mask encompasses the entire inner nasal hood, unlike the Accutron and Matrix, where the outer scavenging caps are perched on top of the nasal hood. Due to the close proximity to the nose and mouth, the Porter/Brown scavenging hood readily captures escaped N_2O . Also noted in this study was that the rubber lining at the periphery of the Porter/Brown nasal hood is very soft and pliable. A better adaptation on the nasal hood to the face was achieved with the Porter/Brown mask due to the soft, pliable rubber hood. This finding also was noted in unsolicited comments from the subjects. With a better seal, one would expect fewer leaks and less release of N_2O into the ambient room air.

It also was observed that as the N_2O flow rate increased, the ambient N_2O level also increased. The only notable exception was the precipitous drop in ambient N_2O levels when high volume evacuation was introduced. This finding is consistent with that of Carlsson et al, who used thermocameras to document N_2O escape during dental procedures.²⁸

An interesting observation is the sharp increase in ambient N_2O during the 9–10 minute interval, which corresponds to time of rubber dam placement. This rapid spike in ambient N_2O was consistent for all three scavenger units and the control. This result could have been anticipated when one considers that as the mouth is opened during rubber dam placement, a plume of N_2O is allowed to escape the oral cavity, rapidly increasing ambient N_2O levels recorded by the Miran sensor.

Christensen et al evaluated proce-

dural influences on ambient N_2O levels.¹² They concluded that rubber dam isolation did not significantly affect the levels of ambient N_2O , even though the reported TWA of ambient N_2O decreased from 192 ppm to 109 ppm following rubber dam placement. The results of this study conflict with their results in that during our sham dental treatment, ambient N_2O levels increased during the period of rubber dam placement regardless of which scavenger unit was used. This finding confirms the result of McGlothlin et al, who demonstrated with infrared imaging that rubber dam placement simply redirected the flow of N_2O out of the sides of the rubber dam.¹² However, this effect was reversed rapidly when high volume evacuation was introduced.

Conclusions

1. Under mock dental treatment conditions, the Porter/Brown scavenger system reduced ambient N_2O levels over the time of N_2O delivery to levels below those recommended by the American Conference of Governmental Industrial Hygienists (50 ppm).

2. Supplemental high volume oral evacuation significantly reduced ambient N_2O levels during dental procedures.

3. Rubber dam application and the corresponding opening of the oral cavity increased ambient N_2O levels. Supplemental high volume oral evacuation can mitigate this effect.

4. The four groups showed no significant difference in diastolic or systolic BP, respiration rate, or pulse rate.

5. N_2O administration did not significantly affect blood oxygen saturation. The average pulse-oximeter (blood oxygen saturation) reading using any of these four methods is 99.1%.

6. The clinical evaluation of the efficacy of three N_2O scavenging units during dental treatment, from most efficient to least efficient, was Porter/Brown, Accutron, and Matrix.

Disclaimer

The authors have no professional, contractual, or monetary relationship with any of the manufacturers mentioned in this article. The study was independently sponsored by a grant from the Virginia Commonwealth University A.D. Williams Committee.

Acknowledgments

This study was sponsored and supported by the Virginia Commonwealth University A.D. Williams Grant Committee. The project was approved by the Western International Review Board: VCUIRB00-A-003.

The authors are grateful to Dr. Al Best, our biostatistician, Virginia Commonwealth University (VCU); CAPT Brian Nicoll, Department of Periodontics, Naval Post Graduate Dental School, Bethesda, Maryland; Ms. Margaret Poland, Research Department, VCU Dental School; and the Department of Environmental Health, VCU for its valuable technical support of this project.

This research was presented as Abstract No. 0173 at the 80th Annual Session of the International Association of Dental Research in San Diego in 2002.

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