Exposure to nitrous oxide in a paediatric dental unit

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Objective. The aim of this study was to evaluate the 8-h time-weighted average (8-h TWA) exposure to nitrous oxide of dentists working in a paediatric dental unit, and to relate this to various operator, patient and environmental factors.

Methods. This prospective, open-label study monitored nitrous oxide levels using either a personal dosimeter or an electronic sensor worn by the operator. Information was recorded by three dental operators administering nitrous oxide/oxygen for inhalational sedation. Thirty-four paediatric dental patients were treated over a total of 17 treatment sessions.

Results. Active scavenging was used for all children; 23 were treated using the Porter-Brown scavenging system and 11 with the Accutron system. Exposure to nitrous oxide expressed as an 8-h TWA ranged from 16 to 374 ppm, with a mean of 151 ppm. The recommended 8-h TWA of 100 ppm was achieved in only 38% of cases. Ambient nitrous oxide levels apparently increased with restorative treatment, poorer behaviour, when the extractor fan was switched off, with patients over 10 years of age and an increased number of sequential patients.

Conclusions. This study found that the recommended 8-h TWA was achieved in only 38% of treatment episodes, despite the use of active scavenging.

Introduction

The use of conscious sedation in dentistry is increasing in response to the General Dental Council guidelines[1], the Poswillo report[2], and more recently, *A Conscious Decision*[3]. It has been estimated that nitrous oxide inhalational sedation (IS) is used by approximately 30–40% of UK dentists[4]. The inhalation sedation technique is well documented, and numerous studies have proven both its immediate and long-term benefit to children with mild to moderate anxiety[5–7], particularly as an alternative to general anaesthesia[8].

Inhalational sedation with nitrous oxide has a good safety record, with minimal effects on the cardiovascular and respiratory systems[9], and few reports of adverse reactions. These have included patient hypoxia as a result of the cylinders being transposed, postoperative reduction in hearing, and nausea and vomiting[10].

Care must be taken, however, to avoid excessive exposure to nitrous oxide by dental personnel. Epidemiological and laboratory animal studies have shown exposure to trace concentrations of nitrous oxide to have a deleterious effect on health[11–13].

In the UK, it has been recommended that exposure should not exceed 100 ppm over an 8-h time-weighted average (8-h TWA) reference period[14]. In air sampling, the TWA is described as the average air concentration of contaminants during a given period, in this case 8 h. Swedish guidelines also recommend an 8-h TWA of 100 ppm, as compared to 25 ppm in the USA, France and Denmark[4,15]. Exposure can be controlled by the use of active scavenging equipment, by minimizing conversation, regularly maintaining the equipment and using fans[11,16]. In paediatric dentistry, controlling nitrous oxide is more difficult: a child talking or crying may increase environmental exposure. Indeed, it has been shown that paediatric dental surgeries may have higher levels of ambient nitrous oxide than those of other specialties[11]. Ambient levels of nitrous oxide have been shown to worsen with decreasing age as well as with successive patients[15]. The

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operative technique can vary exposure. Some studies have suggested that rubber dam can reduce nitrous oxide pollution levels by up to 30%[17], although this has been disputed in others[18–20].

The aim of this study was to evaluate the 8-h TWA exposure to nitrous oxide of dentists working in the Paediatric Dentistry Department of Glasgow Dental Hospital and School (GDHS), Glasgow, UK, and relate this to various operator, patient and environmental factors.

Materials and methods

Ethical approval was not sought for this study because its aim was to evaluate the ambient nitrous oxide concentration within the surgery and no patient intervention was required.

In the Paediatric Dentistry Department of GDHS, the IS sessions are 3 h in duration, with three, one-hour slots available for each child patient. The IS surgeries have no air conditioning, and apart from an extractor fan, air exchange in the surgery is passive. There is an active nitrous oxide scavenging system via a scavenging nosepiece. An extractor fan is present in the surgery and the decision to switch this on is the responsibility of the operating dentist.

Data from three right-handed operating dentists was collected during routine treatment of patients under nitrous oxide/oxygen sedation.

Active scavenging systems used

Porter-Brown (Porter Instrument Company Inc., Hatfield, PA, USA) and Accutron (Accutron Inc., Phoenix, AZ, USA) active scavenging systems were used in conjunction with the corresponding scavenging nosepieces. The scavenging systems were connected via tubing to the standard hospital anaesthetic gas excavation system that has an excavation rate of up to 100 L min^{-1}, which was specially adapted for this purpose. A flow of 45 L min^{-1} has been determined as the optimal required for the capture of gases whilst minimizing noise[21].

Nitrous oxygen concentration monitoring

Recordings of nitrous oxide concentrations were measured using either an electronic monitor (Medigas PM 3010, Environmental Instruments, Lemington Spa, UK) or a personal dosimeter (Molecular Sieve 5A, Markes International, Pontyclun, Mid Glamorgan, UK). The former gives a computerized reading, and measures nitrous oxide levels continuously and logs an average reading at 60-s intervals, whilst the latter is sent for laboratory analysis using gas chromatography. The electronic monitor is supplied with computer software that can convert the information collected and produce a time-weighted average exposure. As the Control of Substances Hazardous to Health (COSHH) guidelines recommendations are based on 8-h TWA, this was the time period over which the authors analysed their results. The personal dosimeters are analysed in the laboratory, and the information obtained produces a cumulative nitrous oxide dose. The time the device has been worn for is recorded, and the 8-h TWA can be calculated by multiplication or division of this total. The monitors were attached to the right-handed dentists' left lapel, since this is the area closest to the patient.

The electronic monitor (Medigas) was used in seven treatment sessions ($n = 17$; mean age = 9 years, age range = 6–15 years) with the Porter-Brown system and calibrated before use. The personal dosimeter (gas chromatography) was used in 10 treatment sessions ($n = 17$; mean age = 11 years, age range = 5–16 years). These were used on four Porter-Brown ($n = 6$; mean age = 9 years, age range = 5–14 years) and six Accutron sessions ($n = 11$; mean age = 13 years, age range = 7–16 years). Exposure was calculated to parts per million (ppm) in an 8-h TWA.

Data collection

Details of the child's visit were recorded on a data sheet. The variables recorded included the date, the duration of nitrous oxide exposure, the patient's age, the combined flow rate of nitrous oxide and oxygen in litres per minute (L min^{-1}), the percentage of nitrous oxide used (i.e. the amount of nitrous oxide used to maintain an adequate level of sedation, expressed as a percentage of the nitrous oxide/oxygen mix), the percentage of the exposure time during which aspiration was used, whether the extractor fan was on or off, rubber dam usage, the

Table 1. Child behaviour during the operative procedure.

Categorical Rating Scale	Number of patients (n = 34)	Missing data (n)*
Crying:		1
(1) screaming	0	
(2) continuous crying	0	
(3) intermittent crying	5	
(4) no crying	28	
Cooperation:		2
(1) violently resists	0	
(2) movement makes treatment difficult	3	
(3) minor movement/intermittent	16	
(4) no movement	13	
Apprehension:		1
(1) hysterical/disobeys all instructions	0	
(2) extremely anxious/disobeys some instructions/delays treatment	4	
(3) mildly anxious/complies with support	16	
(4) calm/relaxed/follows instructions	13	
Sleep:		1
(1) fully awake	33	
(2) drowsy	0	
(3) asleep/intermittent	0	
(4) sound sleep	0	

*All data missing for one patient and cooperation score only missing for one patient.

patient's position, mask fit, and the scavenging system used. The mask fit was rated as poor, adequate or good, as assessed by the operator.

A Categorical Rating Scale[22] was also used to assess behaviour of the child during the visit (Table 1). This scale is easy to use and gives a cumulative score for behaviour over four categories (crying, cooperation, apprehension and sleep), allowing an overall assessment to be made of the child's behaviour in relation to their conscious state.

No formal training was given in applying the Categorical Rating Scale, although it was explained to each operator prior to the start of the study. No assessment of intra- or interexaminer variability was made either.

Statistical analysis

Simple descriptive statistical analysis was used since the sample size was small and a large number of variables were present.

Results

Sample

Data were collected from 17 treatment sessions, and a total of 34 children were treated during this period. The patients ranged in age from 4 to 16 years (mean = 10 years). Eight were seen for acclimatization, 23 for restorative procedures, two for extractions and the treatment was not recorded for one patient.

The duration of treatment ranged between 10 and 65 min (mean = 27 min). Aspiration was used for approximately 14% of the treatment time. Rubber dam was placed on only five of the children; this was mainly for endodontic procedures. The children were in the supine position with the dentist sitting to the right and slightly posterior to them. Nitrous oxide flow rate ranged from 1 to 9 L min^{-1} (mean = 3 L min^{-1}), and the percentage of nitrous oxide used ranged from 30% to 50% (mean = 41%). The extractor fan was switched on during the treatment of 22 children.

Scavenging system used

Active scavenging was used for all 34 children. Twenty-three children were treated whilst the Porter-Brown active scavenging system was in use and the remaining 11 subjects were sedated whilst the Accutron active scavenging system was used. Mask fit was described as 'good' in 13 patients, 'adequate' in seven, 'poor' in two and 'very poor' in one when the

Table 2. Summary of treatment session nitrous oxide use.

Variable	Range	Mean
Duration of N_2O treatment (min)	10–65	27
Age of patient (years)	4–16	10
Flow rate of N_2O/O_2 mixture (L min^{-1})	1–9	31
Mixture of nitrous oxide (%)	30–50	41
Treatment time of aspirator used (%)	0–100	14
8 hour TWA N_2O exposure (ppm)	16–374	163
8 hour TWA using Accutron scavenging system with badge dosimeters (ppm)	47–269	206
8 hour TWA using Porter-Brown scavenging system with badge dosimeters (ppm)	51–374	204
8 hour TWA using Porter-Brown scavenging with Medigas monitor (ppm)	16–203	109

Porter-Brown system was used. The mask fit when the Accutron system was used was judged as 'excellent' in one, 'good' in six and 'adequate' in the remaining four patients.

Behaviour

All of the children were fully awake throughout the sedation session. Categorical Rating Scale scores ranged from 7 to 13 (mean = 11). Scores are detailed in Table 1.

Ambient nitrous oxide time-weighted average

With respect to 8-h TWA nitrous oxide exposure, this ranged from 16 to 374 ppm, with a mean of 152 ppm. The electronic sensor (Medigas) recorded levels ranging from 16–203 ppm and the personal dosimeters (gas chromatography) recorded levels ranging from 47 to 374 ppm. The results are further detailed in Table 2.

Twenty-one (62%) patients produced 8-h TWA nitrous oxide levels of greater than the COSHH recommended limit of 100 ppm, and when analysed by individual treatment sessions, seven (41%) were below the recommended level. The comparison of the treatment episodes where 8-h TWA exposure was under 100 ppm against those that were greater than 100 ppm is detailed in Table 3.

Exposure apparently increased with: restorative treatment; poor behaviour; switching the fan off; nitrous oxide flow rates of ≤ 3 L min^{-1}; children aged > 10 years; when the aspirator was used; with the Accutron system; and increasing numbers of sequential patients.

Table 3. Summary of patient variables during nitrous oxide treatment in relation to 8-h time-weighted average.

Variable	Number of patients	Number of patients (%) 8-h TWA < 100 ppm	8 h TWA > 100 ppm
Total (*n*):			
patients	34	13 (38)	21 (62)
treatment sessions	17	7 (41)	10 (59)
Scavenging system:			
Accutron	11	2 (18)	9 (82)
Porter-Brown	23	11 (48)	12 (52)
Measuring device:			
dosimeter	17	5 (29)	12 (71)
Medigas	17	8 (47)	9 (53)
Fan:			
on	22	11 (50)	11 (50)
off	12	2 (17)	10 (83)
Treatment:			
acclimatization	8	4 (50)	4 (50)
cons	23	6 (26)	17 (74)
extractions	2	1 (50)	1 (50)
Categorical Rating Scale:			
10	7	1 (14)	6 (86)
> 10	25	10 (40)	15 (60)
N_2O%:			
30%	7	1 (14)	6 (86)
> 30%	26	11 (42)	15 (58)
Flow rate (L min^{-1}):			
3	20	5 (25)	15 (75)
> 3	13	7 (54)	6 (46)
Aspirator used:			
yes	16	4 (25)	12 (75)
no	10	4 (40)	6 (60)
Rubber dam:			
used	5	2 (40)	3 (60)
not used	29	11 (38)	18 (62)
Mask fit:			
excellent	1	0 (0)	1 (100)
good	19	8 (42)	11 (58)
adequate	11	4 (36)	7 (64)
poor	2	1 (50)	1 (50)
very poor	1	0 (0)	1 (100)
Age (years):			
< 10	18	9 (50)	9 (50)
> 10	16	4 (25)	12 (75)
Number of patients treated per session:			
1	3	2 (67)	1 (33)
2	17	8 (47)	9 (53)
3	14	3 (21)	11 (79)

*Data missing as follows: treatment performed missing for one child; Categorical Rating Scale score missing for two children; percentage nitrous oxide missing for one child; flow rate missing for one child; and whether aspiration used missing for eight children.

Discussion

The sample included a wide range of children with respect to both their age and to the treatment that was provided, and this is representative of the children referred to the paediatric unit of GDHS. All patients had their treatment carried out successfully and this confirms the value of this type of sedation in managing anxious children. A previous study of referral patterns to the department showed that 34% were referred because of management difficulties, with the peak age for referral being between 8 and 10 years[23]. This is similar to the reported referral patterns in a paediatric dental department of a dental school in the North of England[24].

Despite the use of active scavenging, the recommended 8-h TWA was achieved in only 38% of cases, even though the dental operator for the majority of patients rated the fit of the nasal mask, irrespective of type, as 'good'. Moreover, the majority of the children were well behaved, even though the findings suggest that exposure increased when behaviour was poor. Previous studies have shown that increased concentrations of ambient nitrous oxide occur when the patient's behaviour is poor[20,25].

This study suggests that restorative treatment in children is associated with higher exposure levels than tooth extraction; previous studies have not investigated this. Only a few patients had extractions performed, and therefore, this should be regarded with caution. Restorative treatment may be responsible for higher levels of exposure since the child holds their mouth open for a longer time and the operator is in closer proximity to the patient's breathing zone during these procedures. However, a thermocamera study showed that nitrous oxide is only released during mouth opening with deliberate exhalation[26]. The use of rubber dam did not appear to limit exposure, but it was only used a few times in this study, and given the overall sample size, this finding is also inconclusive. Some previous studies have shown a reduction in ambient nitrous oxide concentration[17] when rubber dam is used, whilst others have found no difference in concentrations when it is employed[18–20].

Exposure was seen to be higher in those children over the age of 10 years. This is in contrast to the evidence found in a study by Girdler and Sterling[15], although their study was carried out using children undergoing dental extractions. In this study, the older children may have received more restorative treatment, resulting in increased exposure by the mechanisms previously described. This study found that high-volume aspiration was also associated with increased exposure levels and this finding may also be partly related to the fact that this was used when restorative treatment was carried out.

In the present study, the Accutron system also appeared to be associated with higher levels of ambient nitrous oxide; however, it is impossible to verify this. The study was not designed to test one scavenging system against the other, and discrepancies such as those mentioned above and the cohort of patients seen using this system may have contributed to this finding. In this study, the use of an extractor fan appears to have decreased the exposure levels; the fan may have increased the air circulation through the room and thereby removed some of the residual gas. A previous study also found that the use of a fan decreased ambient nitrous oxide levels[11]. Nitrous oxide is heavier than air, and sinks to floor level, and therefore, floor-level excavation may be more efficient at removing waste gases.

Increased levels of exposure were seen when more children were treated consecutively, with 79% of all the sessions where all three children attended producing 8-h TWA values greater than 100 ppm for the session. Other studies have shown that environmental nitrous oxide levels not only take some time to dissipate, but also increase with successive patients[15] and with duration of nitrous oxide gas administration, despite active scavenging[16].

The major limitation of this study is that there were many variables present that could have influenced the results. Moreover, the relatively small sample size renders multivariate analysis inappropriate. Prominent amongst these variables, is the fact that two different active scavenging systems and two different methods of nitrous oxide detection were used.

The reason for this was that the GDHS Department of Child Dental Health were trying to decide which active scavenging system they wished to buy during an upgrade of the dental surgeries, and therefore, both systems were in use. Therefore, even though this is a larger sample than previous studies[16,20,24], these results have to be interpreted with caution. Because this was a pilot study, no sample size calculation was undertaken, although this would be advisable in future studies to ensure the validity of the results. Other paediatric IS service providers who routinely monitor nitrous oxide environmental exposure levels are similarly advised to consider their methodology.

There is no standard method of measuring nitrous oxide in the dental environment. Witcher *et al*. used an infrared nitrous oxide analyser positioned within 15–25 cm of the operator's nose[11]. Henry *et al*.[16,20] used an infrared spectrophotometer placed at 50–56 cm from the operator's nose, whilst McGlothin *et al*. used a thermal camera[19]. In this study, the choice of sensor was determined by cost and availability, in the naïve belief that every monitor would produce the same result and that the position of the monitor alone (i.e. the left lapel on right-handed operators, since this is the area closest to the patient's breathing zone for right-handed operators) would suffice to ensure reliability. The electronic monitor (Medigas), in particular, is easy to use, commercially available and does not need the support of a medical physics laboratory service. Some very large exposure levels were noted (e.g. > 500 ppm) during the initial stages of the sedation period, but the device response time was slow, taking many minutes to record low exposure levels even when removed from the dental surgery altogether. This suggests that the exposure level recorded erred on the high side. Further research is required to test this assumption, and clearly, a standard method of measuring nitrous oxide exposure has to be developed for dentistry.

In this study, the authors found it difficult to adhere to the UK recommendations of 100 ppm over an 8-h TWA. Other researchers have reported that they were unable to keep the ambient nitrous oxide levels below the COSHH recommendation even when using active scavenging[16,24,25]. Girdler and Sterling did report that the 8-h TWA remained below 100 ppm, but the treatment sessions studied were of shorter durations than those in this study[15]. It may be that it is difficult to achieve an 8-h TWA level of < 100 ppm in the paediatric dentistry environment. The authors recommend that further research is undertaken to determine the best method of measuring and limiting nitrous oxide environmental exposure so that guidelines can be developed to ensure safe practice in the paediatric dentistry environment.

What this paper adds
- Information about N_2O levels in paediatric dentistry operative treatment.
- Provides an alert for dental operators about N_2O exposure despite scavenging.

Why this paper is important to paediatric dentists
- This paper demonstrates that frequent monitoring of N_2O levels is essential.
- Provides a springboard for future research in this area.

Conclusion

This study found that the recommended 8-h TWA was achieved in only 38% of treatment episodes studied, despite the use of active scavenging. Exposure apparently increased when restorative treatment was performed, with poorer behaviour, when the extractor fan was switched off, when patients were aged over 10 years and when sequential patients were treated.

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