Safety of High-Concentration Nitrous Oxide by Nasal Mask for Pediatric Procedural Sedation

Experience With 7802 Cases

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Objectives: Nitrous oxide is an effective sedative/analgesic for mildly to moderately painful pediatric procedures. This study evaluated the safety of nitrous oxide administered at high concentration (up to 70%) for procedural sedation.

Methods: This prospective, observational study included all patients younger than 18 years who received nitrous oxide for diagnostic or therapeutic procedures at a metropolitan children's facility. Patients' age, highest concentration and total duration of nitrous oxide administration, and adverse events were recorded.

Results: Nitrous oxide was administered on 7802 occasions to 5779 patients ranging in age from 33 days to 18 years (median, 5.0 years) during the 5.5-year study period. No adverse events were recorded for 95.7% of cases. Minor adverse events included nausea (1.6%), vomiting (2.2%), and diaphoresis (0.4%). Nine patients had potentially serious events, all of which resolved without incident. There was no difference in adverse event rates between nitrous oxide less than or equal to 50% and greater than 50% ($P = 0.18$). Patients aged 1 to 4 years had the lowest adverse event rate ($P < 0.001$), with no difference between groups younger than 1 year, 5 to 10 years, and 11 to 18 years. Compared with patients with less than 15 minutes of nitrous oxide administration, patients with 15 to 30 minutes or more than 30 minutes of nitrous oxide administration were 4.2 (95% confidence interval, 3.2–5.4) or 4.9 (95% confidence interval, 2.6–9.3) times more likely to have adverse events.

Conclusions: Nitrous oxide can be safely administered at up to 70% concentration by nasal mask for pediatric procedural sedation, particularly for short (<15 minutes) procedures. Nitrous oxide seems safe for children of all ages.

Key Words: nitrous oxide, procedural sedation, analgesia, adverse events

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Inadequate relief of children's procedural pain and distress not only affects the experience of children and their parents in the emergency department, but also adversely impacts procedural success.[1] In addition, children's response to aversive medical procedures may have significant consequences for their subsequent medical experience. Children who experience high degrees of distress during a lumbar puncture, for example, may develop exaggerated negative memory of the event that, in turn, predicts greater distress during a subsequent lumbar puncture.[2] Inadequate analgesia has been shown to diminish the effect of adequate analgesia for subsequent painful procedures.[3] These findings are not surprising given the large contribution of anticipatory anxiety to pain report and pain tolerance in children and adolescents.[4] Fortunately, memory may also be impacted in a positive way by interventions aimed at reducing pain and distress during medical procedures. These interventions result in decreased anticipatory and procedural distress with subsequent procedures.[5] Because adolescent and adult health care behaviors are influenced by childhood medical experience, success in alleviation of pediatric procedural pain may have long-term implications.[6]

For many years, members of the dental profession have recognized the ability of inhaled nitrous oxide (N_2O) to reduce children's pain and improve behavior during dental treatment.[7–9] Providing comfort with N_2O at an initial dental visit impacts children's later experience, resulting in improved behavior and less anxiety at subsequent visits.[10–12] This effect can be seen even if N_2O is not administered at the later visit.[10]

The utility of N_2O as a sedative/analgesic for mildly to moderately painful pediatric medical procedures including laceration repair, fracture reduction, peripheral venous catheter insertion, and lumbar puncture has been reported.[13–16] Although the safety of a fixed 50% N_2O/50% oxygen mixture for procedural sedation has been demonstrated in studies encompassing thousands of patients,[17–21] less information is available regarding the safety of N_2O administered in higher concentration.[22,23] This single-center, multisite, prospective, observational study was performed to assess the safety profile of N_2O administered at up to 70% concentration for procedural sedation in a large pediatric population. We hypothesized that patient age, maximum concentration, and length of administration have no impact on adverse event rate.

METHODS

Approval was obtained from the institutional review board of the Children's Hospitals and Clinics of Minnesota for this prospective cohort study. Informed consent was waived given the observational study design. All children 18 years and younger who received N_2O sedation/analgesia for diagnostic studies and/or therapeutic procedures from September 2004 to March 2010 at the Children's Hospitals and Clinics of Minnesota were enrolled in the study. Children were excluded when no attempt at sedation was made because of acute illness or specific N_2O contraindication identified during presedation assessment. Patients were also excluded when presedation nursing assessment indicated that a deeper level of sedation than that usually afforded by N_2O would be required to achieve the desired outcome (eg, a child who would not readily accept the mask during presedation assessment for a procedure requiring a high degree of immobility such as temporal bone computed tomography). The number of patients rejected for N_2O sedation based on presedation assessment was not recorded. Nitrous oxide sedation/analgesia was administered in the emergency departments, radiology departments, short-stay units, hematology/oncology clinics, and special diagnostic units on the Minneapolis, St. Paul, and Minnetonka campuses of the Children's Hospitals and Clinics of Minnesota.

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Nurse-Administered N_2O Program

Registered nurses trained and experienced in monitoring moderately and deeply sedated pediatric patients underwent additional institutional training in N_2O sedation administration. This training included attendance at a didactic course designed to address the pharmacology, toxicity, and environmental safety of N_2O as well as the equipment used for its delivery. The course was based on requirements prescribed for state licensure of dentists and dental hygienists for N_2O administration. After successful completion of the course, nurses received additional hands-on training in a mentored setting until clinical competency was demonstrated. Although N_2O is an inhaled medication, this program met the guidelines of the American Nurses' Association for registered nurses charged with the management of patients receiving intravenous medication for short-term diagnostic procedures.[24]

N_2O Administration

All patients underwent a presedation assessment to identify potential contraindications to sedation using the American Society of Anesthesiologists' classification and an institution-specific airway score based on absence (class 1) or presence (class 2) of historical elements or features that might place them at risk for airway compromise during sedation, including current stridor, snoring, obstructive sleep apnea, morbid obesity, craniofacial malformation, symptomatic asthma or heart disease, gastroesophageal reflux disease, swallowing dysfunction, or previous airway problems with sedation or anesthesia.[25] Patients were screened for specific contraindications to inhaled N_2O, including gas in a trapped space (eg, pneumothorax, bowel obstruction, recent craniotomy, or retinal surgery), pregnancy, increased intracranial pressure, and altered level of consciousness. Patients were also screened for history of bleomycin administration because a minimum of 30% oxygen is administered with the N_2O. Vital signs, including temperature, respiratory rate, heart rate, blood pressure, and baseline pulse oximetry reading, were obtained during the presedation assessment. Inhaled N_2O was administered via a standard dental flow meter (Porter Instrument Company, Hatfield, Pa; or Accutron, Inc, Phoenix, Ariz) that allowed titration of N_2O concentration from 0% to a maximum of 70%, with oxygen as the remaining gas. The equipment incorporates built-in safety features, including a nonrebreathing valve, emergency air intake valve, and failsafe device that automatically terminates the flow of N_2O in the event of an interruption in oxygen flow. The equipment includes an apparatus for exhaled gas scavenging and evacuation to minimize risk of occupational exposure to N_2O. A dental-type nasal mask (Accutron, Inc) was used for N_2O administration. An adequate seal could be comfortably maintained using the nasal mask over the nose of the older child or over the nose and mouth of a toddler.

Starting concentration and titration of N_2O were at the discretion of the sedation nurse. Although not under protocol, current practice is to begin administration at 60% N_2O/40% oxygen with titration to higher or lower concentration within 2 to 3 minutes based on the patient's response to the procedure. Maximum allowable N_2O concentration was 70%. Distraction (eg, storytelling, soothing discourse) was provided to all children throughout the procedure. After procedure completion, 100% oxygen was administered for 2 to 5 minutes to minimize risk of diffusion hypoxia and to direct additional exhaled N_2O to the scavenging system. Throughout the N_2O administration, and until the child returned to presedation level of alertness, the child was monitored with continuous pulse oximetry and direct nursing observation.

Our nurse-administered protocol dictates that N_2O be administered either (1) as a single agent or (2) titrated to maintain a minimal level of sedation if a potentially sedating medication was given before N_2O administration. During the first 4 months of this study, children were required to fast for 4 hours before administration of N_2O. After this period, children scheduled for elective procedures with N_2O were advised to have, at most, a light meal during the 4 hours before their procedure. Interim analysis 6 months after this change in practice revealed no difference in adverse event rate between the 2 groups. No additional fasting information was collected for this study.

Outcome Assessment

Adverse event data were collected using a quality audit tool designed to assess the safety of N_2O for procedural sedation. This tool was modeled after one previously used to report institutional experience with propofol sedation.[25] The nurse responsible for N_2O administration completed a quality audit tool for each patient receiving N_2O regardless of procedural success. Quality audit sheets were attached to each N_2O sedation order to ensure compliance with data collection. Adverse event choices were none, apnea, oxygen saturation less than 92%, diaphoresis, nausea, vomiting, and "other." Chart reviews were triggered by the following: apnea, oxygen saturation less than 92%, and "other" adverse effect. In addition to adverse event data, demographic information was collected including date of birth and date of stay. Notation of procedure performed was restricted to checkboxes corresponding to the list in Table 1. Nitrous oxide administration data included highest concentration of N_2O administered (≤50% or >50%) and total duration of N_2O administration (<15, 15–30, or >30 minutes). Level of sedation and ability to successfully complete the procedure were not included in the data collection for this study.

Adverse effects were categorized as reported by the Pediatric Sedation Research Consortium (PSRC) for analysis of multi-institutional sedation practices, where "serious" adverse events included death, cardiac arrest, and aspiration.[26] "Potentially serious" PSRC adverse events included those "which

TABLE 1. Patient and Procedure Characteristics

	n (%)
Age, y	
<1	116 (1.5)
1–4	3751 (48.1)
5–10	3050 (39.1)
11–18	885 (11.3)
Procedure	
Urinary catheterization	4928 (63.6)
Peripheral venous cannulation	826 (10.7)
Lumbar puncture	340 (4.4)
Noninvasive procedure (eg, echocardiogram, computed tomographic scan)	206 (2.7)
Enteral tube (eg, nasogastric, gastrostomy) placement	197 (2.5)
Peripherally inserted central catheter placement	100 (1.3)
Minor surgical procedure (eg, abscess incision and drainage)	72 (0.9)
Laceration suturing	52 (0.7)
Bone marrow biopsy	2 (0)
Other (eg, electromyelogram, botulinum toxin injection)	1020 (13.2)

TABLE 2. Total Adverse Events During Nitrous Oxide Administration

Adverse event,* n (%)	
No adverse events	7470 (95.7)
Apnea	0
Oxygen saturation <92%	8 (0.1)
Diaphoresis	33 (0.4)
Nausea	128 (1.6)
Vomiting	171 (2.2)
Other	59 (0.8)
Description of "other" complications, n	
Agitation/combative/upset and crying/inadequate sedation	33
Gagging	6
Stomachache and/or pallor	4
Seizure	3
Scared/fearful	3
Headache	2
Prolonged sedation/drowsy after procedure	2
"Shaky extremity" after sedation	1
Unable to access vein	1
Eyes rolled, vomited after procedure	1
Head jerking, unable to respond but recalled procedure	1
Itchy tongue, jaw pain after asparaginase injection	1
Incontinent	1

*Total is more than 100% because patients could have more than 1 adverse event recorded.

could progress to poor outcomes if not managed well," including stridor, laryngospasm, airway obstruction, wheezing, or central apnea. Although not considered a potentially serious event for the purposes of the PSRC report, oxygen desaturation less than 92% was included as a "potentially serious" event for the current study as it is an atypical event for N_2O sedation.

Analytic Approaches

Frequency distribution was used to describe patients' characteristics, procedures conducted, and adverse effects; and median (range) was used to describe the continuous data such as patient age. χ^2 test or Fisher exact test was used to compared the adverse effects by age, length of N_2O administration, and maximum concentration of N_2O administered. To assess the impact of individual factors, a logistic regression model was fit with any adverse effect as the dependent variable and age, length of administration, and maximum concentration as independent variables. A 2-sided $P < 0.05$ was used for significance. All analyses were conducted with SPSS V15.0 (SPSS, Chicago, Ill).

RESULTS

Nitrous oxide was administered on 7802 occasions to a total of 5779 patients during the 5.5-year study period. Patient and procedural characteristics are listed in Table 1. Patients ranged in age from 33 days to 18 years, with a median age of 5.0 years. Nitrous oxide was administered at greater than 50% on most occasions (90.8%, n = 6947). Most administrations were short (<15 minutes: 89.3%, n = 6896), with 9.7% (n = 750) lasting 15 to 30 minutes and 1.0% (n = 80) lasting more than 30 minutes.

Total adverse effects are listed in Table 2. Comparison of adverse events with age at time of N_2O administration is shown in Table 3. "Other" events in the younger than 1-year group included agitation (n = 4) and gagging (n = 1). With the exception of diaphoresis, there was no difference in adverse effects between N_2O administered at less than or equal to 50% compared with greater than 50% (Table 4). The incidence of adverse effects was higher when N_2O was administered for more than 15 minutes (Table 4). This was true for all age groups. On the basis of the logistic regression model, duration of N_2O administration had the most impact on adverse events after adjusting for age and N_2O concentration. Patients with 15 to 30 minutes or more than 30 minutes of N_2O administration were 4.2 (95% confidence interval [CI], 3.2–5.4) or 4.9 (95% CI, 2.6–9.3) times more likely to have adverse effects as patients with less than 15 minutes of N_2O administration. Patients receiving N_2O for more than 15 minutes did not cluster into procedural groups for which adverse events such as vomiting would be otherwise predicted: 27.5% urinary catheterization, 18.1% other (eg, electromyelogram, botulinum toxin injection), 17.5% peripheral venous cannulation, and less than 10% in each of the remaining procedural groups.

Nine patients had potentially serious adverse events. Four patients had brief oxygen desaturation from 79% to 89% that promptly resolved with increased supplemental oxygen and no other intervention. One child with a history of gastroesophageal reflux and previous aspiration received oropharyngeal suctioning in addition to increased supplemental oxygen for a brief oxygen desaturation to 76% associated with a "gagging episode." One tracheostomy-dependent child became agitated

TABLE 3. Adverse Events by Age Group

Adverse Event, n (%)	Group 1: <1 y (n = 116)	Group 2: 1–4 y (n = 3751)	Group 3: 5–10 y (n = 3050)	Group 4: 11–18 y (n = 885)	*P*
Apnea	0	0	0	0	N/A
Oxygen saturation <92%	1 (0.9)	5 (0.1)	2 (0.1)	0	0.12
Diaphoresis	0	14 (0.4)	11 (0.4)	8 (0.9)	0.19
Nausea	N/A	35 (0.9)*	60 (2.0)	33 (3.7)	<0.001
Vomiting	1 (0.9)	73 (1.9)	77 (2.5)	19 (2.1)	0.36
Other	5 (4.3)†	18 (0.5)	23 (0.8)	13 (1.5)	0.001
Any adverse event	6 (5.2)	121 (3.2)‡	146 (4.8)	59 (6.7)	<0.001

*Different from group 4 but not different from group 3; no difference between groups 2 and 3.

†Different from groups 2 and 3 but not different from group 4.

‡Different from other 3 groups, with no difference between other 3 groups.

N/A indicates not applicable.

TABLE 4. Adverse Events by Maximum Nitrous Oxide Concentration or Length of Administration

	Maximum Concentration			Length of Administration			
Adverse Event, n (%)	≤50% (n = 700)	>50% (n = 6947)	*P*	Group 1: <15 min (n = 6896)	Group 2: 15–30 min (n = 750)	Group 3: >30 min (n = 80)	*P*
Apnea	0	0	N/A	0	0	0	N/A
Oxygen saturation <92%	0	8 (0.1)	1.0	6 (0.1)	2 (0.3)	0	0.24
Diaphoresis	8 (1.1)	23 (0.3)	0.001	18 (0.3)*	14 (1.9)	1 (1.3)	<0.001
Nausea	13 (1.9)	113 (1.6)	0.65	70 (1.0)*	48 (6.4)	9 (11.3)	<0.001
Vomiting	16 (2.3)	150 (2.2)	0.83	110 (1.6)†	56 (7.5)	3 (3.8)	<0.001
Other	8 (1.1)	50 (0.7)	0.22	51 (0.7)	7 (0.9)	1 (1.3)	0.39
Any adverse event	37 (5.3)	287 (4.1)	0.15	223 (3.2)*	96 (12.8)	12 (15.0)	<0.001

*Different from groups 2 and 3 but no difference between groups 2 and 3.

†Different from group 2 but not different from group 3.

while receiving 100% oxygen after the procedure and had a decrease in oxygen saturation to 35% accompanied by increased tracheostomy secretions. The child's condition promptly returned to baseline status with calming and tracheostomy suctioning.

Three developmentally appropriate patients developed brief (<3 minutes), generalized tonic-clonic seizure activity, 1 during N_2O administration and 2 while receiving 100% oxygen after the procedure. One child was receiving N_2O sedation for peripheral intravenous catheter placement before cranial magnetic resonance imaging for evaluation of her seizure disorder. One otherwise healthy child had a history of a previous nonfebrile "spell" suspicious for seizure activity several months before this event. The third had no previous history of neurologic abnormality. Two of these patients had oxygen saturation down to 78% to 79% during clinical seizure activity resolving with increased supplemental oxygen and, in 1 case, oral suctioning for a small amount of thin secretions. Conditions of all 3 patients returned to baseline clinical status, and they were discharged to home later the same day.

There were no apnea events recorded. No patients required airway adjuncts, bag-mask ventilation, or intubation. No child required admission for sedation-related events.

DISCUSSION

Nitrous oxide is an inhaled agent that has provided comfort for dental patients for more than 150 years. Several properties make N_2O appealing for pediatric procedural sedation. Rapid onset of action and rapid return to baseline function allow precise targeting of peak effect to timing of the procedure. Other advantageous effects of N_2O include analgesia, amnesia, and anxiolysis. Although initially rejected by the medical profession as a single-agent anesthetic because of its lack of potency, N_2O has gained popularity during the past several years as a sedative/analgesic for a variety of pediatric medical procedures.[13–16,27–30]

The desire to minimize pain and distress during medical procedures, however, must be weighed against the obligation to ensure patient safety. Adverse event data from several large (>500 patients) studies of N_2O for sedation/analgesia are summarized in Table 5. Unfortunately, lack of consistent definition of adverse events or method of data collection makes comparison between these studies difficult. For example, 1 report of 1019 patients listed an adverse event rate of 37%; however, these adverse events included euphoria in 20.1% and dreaming in 5.7% of patients.[17] Although, anecdotally, several of our patients report having "dreams" during N_2O administration, such a response could be considered a reasonable reaction to the distraction and storytelling provided while children remain in a minimally sedated state. Adverse effects reported in the current study were generally mild. Even potentially serious adverse events were either self-limited or responded to initiation of increased supplemental oxygen.

The reported incidence of adverse effects compared with age at the time of N_2O administration for procedural sedation

TABLE 5. Studies of Nitrous Oxide for Pediatric Sedation

Study	Nitrous Oxide–Oxygen Ratio	Major, Serious, or Potentially Serious Adverse Events,* %	Minor Adverse Events,* %	Total No. Patients†
Annequin et al[17]	50:50	0	37	1019
Gall et al[18]	50:50	0.33	5	7511
Kalach et al[19]	50:50	0	8.6	600
Hennequin et al[20]	50:50	0	6.2	1205‡
Onody et al[21]	50:50	0.08	4.4	35,828§
Babl et al[22]	Up to 70:30	0.3	8.3	762
Current study	Up to 70:30	0.14	5.0	7802

*Either undefined or defined a priori by the study authors with exception of Onody, who based definitions on standards from the European Agency for the Evaluation of Medicinal Products (now known as European Medicines Agency). See text for current study definition.

†All children unless otherwise specified.

‡Includes adults with intellectual disability and children.

§Includes 29,471 patients from "pediatric units."

also varies by study. Gall et al[18] noted a higher rate of major adverse events, defined as respiratory events (eg, oxygen desaturation, airway obstruction, apnea), cardiovascular events (eg, bradycardia), or oversedation with loss of verbal contact during the procedure or persistence of sedation for longer than 5 minutes after discontinuation of N_2O, in children younger than 1 year (2.3%) compared with other age groups. In contrast, the study of Onody et al[21] found a higher incidence (5.6%) of total adverse events in the 11- to 18-year-old children compared to the younger children (1.7% for 0–1 years, 2.3% for 1–4 years, and 4.2% for 5–10 years). Kalach et al[19] found no correlation between age and adverse events in their study, which included patients as young as 3 months. Our study found a lower incidence of adverse events in the 1- to 4-year-old group compared to the other age groups. Difficulty assessing nausea in the 1- to 4-year-old group may account for some of this difference. Total adverse event rate in children younger than 1 year was not different from the 5- to 10- or 11- to 18-year age groups.

With the exception of diaphoresis, which was higher in the low-concentration group, we found no difference in incidence of adverse effects at less than or equal to 50% N_2O compared with higher concentration. This supports the findings of Babl et al[22] who also found no difference in adverse event rate between the 2 concentrations.

We did find an increased incidence of nausea, vomiting, and diaphoresis with more than 15 minutes of administration time. Onody et al[21] also found an increased incidence of adverse events when N_2O was administered for more than 10 minutes compared to less than 10 minutes. No correlation was seen between time of administration and adverse events in 2 other studies.[17,19]

In accordance with institutional policy for minimal sedation, patients were not required to fast before nitrous oxide administration; therefore, information regarding correlation between adverse effects and time to last oral intake is unavailable for this study. Previous reports, however, have shown no correlation between fasting state and adverse events with nitrous oxide sedation in children.[31,32]

There are limitations to the present study. As part of the system-based training for N_2O, sedation nurses were given specific instruction regarding accurate completion and importance of the quality audit tool. Despite this, it is likely that a tool was not completed for every patient receiving N_2O sedation. Because data on frequency of completion of the tool were not collected, the potential impact of incomplete reporting on the study outcome is difficult to quantify. Adverse events, particularly minor ones, may be underreported when based on nurse reports.[33] Documentation of apnea was based on clinician observation, which may underestimate the frequency of this event compared to capnography.

Data elements in the quality audit tool were limited to prescribed choices. Constraint of N_2O concentration choice to less than or equal to 50% or more than 50% was based on the determination of the American Academy of Pediatrics that minimal sedation is provided at less than or equal to 50% with potential increased risk when used at greater than 50% concentration.[34] Although simplifying data collection and minimizing impact on nursing workflow, these constraints may oversimplify the data for patients whose N_2O concentration was titrated during the sedation experience. For example, a patient receiving N_2O at greater than 50% concentration for only a short portion of a procedure lasting 40 minutes would still fall into the greater-than-50% N_2O concentration, more-than-30-minute group for study purposes.

Adverse events that did not fit into the prescribed choices required the selection of "other" and relied on chart review for description, perhaps leading to underreporting of effects such as euphoria seen in other studies. However, 3 patients with an atypical adverse event, seizures temporally associated with N_2O administration, were identified using this process. These patients are described in more detail elsewhere.[35] Although temporally related to the nitrous oxide administration, causality between N_2O and seizures in the current study patients is indeterminate. Only 1 case report has clearly linked N_2O inhalation with the onset of electroencephalographic and clinical seizure activity in a child.[36]

Although this is the largest report of adverse events in children receiving inhaled N_2O in concentration up to 70%, it is important to note that a dental "nasal" mask, not a full face mask, was used for gas delivery. Our patients are instructed to breathe through the nose while keeping the mouth closed; however, room air may be entrained resulting in decreased inspired N_2O concentration compared to the flow meter setting.[37] Although it was possible to cover both the nose and mouth of smaller patients with this "nasal" mask, the triangular shape and lack of a circumferential air cushion, as found in more traditional "anesthesia" face masks, likely allowed entrainment of room air with dilution of administered N_2O even in these patients. Current study information, therefore, may not be generalized to patients given high-concentration N_2O via a full face mask system. Safety information also cannot be generalized to the use of N_2O in combination with other sedating medications.

This study adds to the body of literature supporting the safe use of N_2O for pediatric procedural sedation. Nonetheless, it should be noted that some of the most serious potential adverse effects of N_2O administration are also the rarest. Rigorous screening of patients for specific contraindications to N_2O administration, such as gas trapped in an enclosed space, is essential. Administration of N_2O to patients with pneumothorax or bowel obstruction may lead to expansion of gas with readily apparent adverse consequences; other areas of trapped gas may not be so clinically apparent. Patients who have undergone recent retinal surgery may have intraocular gas that may expand during N_2O administration, leading to intraocular hypertension and irreversible loss of vision.[38] Patients who have undergone supratentorial craniotomy may have enough residual intracranial air to place them at risk for complications if N_2O is administered within the first 3 weeks after surgery.[39]

Other potential adverse events such as myeloneuropathy associated with N_2O administration to a vitamin B_{12}–deficient patient, may be rarer still, yet providers offering N_2O sedation should be aware of this potentially serious complication.[40] Serious adverse events including cardiac arrest have been attributed to inappropriate use of a N_2O administration device and insufficient patient monitoring,[21] emphasizing the importance of adherence to appropriate sedation guidelines even when a minimal sedation agent such as N_2O is used.

In conclusion, the present data support the notion that N_2O can be safely administered at up to 70% concentration by nasal mask for pediatric procedural sedation. Nitrous oxide seems safe for children of all ages, including those younger than 1 year. This study neither addresses the efficacy of the sedation nor attempts to define optimal N_2O concentration for particular procedures.

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