Exposure of Anesthesiologists to Nitrous Oxide during Pediatric Anesthesia

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Abstract: Nitrous oxide (N₂O) is one of the most common inhalation anesthetics in current anesthesiological practice. Even though artificial ventilation and active scavenging in operating theaters are employed in most of the modern hospitals, potential N₂O contamination persists in regular anesthesia, particularly pediatric operation. In order to understand personal exposure during pediatric anesthesia, ambient monitoring for N₂O exposure around the breathing zone of the anesthesiologist was conducted by a portable infra-red Miran 1B2 spectrophotometer. The results demonstrated that general mask anesthesia generated greatest N₂O contamination, with the mean time-weighted-average (TWA) concentrations of 85 ± 48.4 (mean $\pm$ S.D.) ppm in 12 cases. Initial mask induction followed by cuffed endotracheal intubation (6 cases) or intravenous induction followed by uncuffed endotracheal intubation (6 cases) also produced significant pollution to the workers, with the mean TWAs of 33.2 ± 24.0 ppm and 31.9 ± 18.0 ppm respectively. These procedures provided exposure levels above the 25 ppm Recommended Exposure Limit (REL) of the National Institute of Occupational Safety and Health (NIOSH), U.S.A.¹⁾ Modification with intravenous induction followed with cuffed endotracheal intubation or mask general anesthesia provided with a ventilation hood diminished the contamination apparently, with the resulting mean TWAs of 11.0 ± 4.7 ppm and 17.9 ± 9.8 ppm in 7 and 5 cases respectively. The results indicated that excessive N₂O exposure to anesthesiologists was not negligible during routine pediatric anesthesia. Significant reduction could be achieved via appropriate industrial modification.

Key words: Nitrous oxide, Anesthetics, Pediatric, Anesthesia, Anesthesiologist, Exposure

Introduction

Exposure to trace concentrations of waste anesthetics has been considered hazardous for the anesthesiologists or surgical personnel since 1960s that adverse reproductive outcomes were observed in female workers in operating rooms²⁾. Several epidemiological studies have further identified increased prevalence of renal and hepatic damage³⁾, infertility⁴⁾, reproductive difficulties⁵⁾, congenital anomalies and fetal growth retardation⁶⁾ for those with occupational

anesthetic exposure. Increased sister chromatid exchange⁷⁾, chromosomal aberrations^{8, 9)} or DNA single strand breaks¹⁰⁾ were also observed in the peripheral lymphocytes of those with occupational exposure to various anesthetics, including N₂O, halothane and isoflurane *et al.* Recently, we have also demonstrated that nurses in anesthetic department with chronic occupational N₂O exposure carried significantly higher frequencies of cytogenetic damage; i.e., micronucleus in the lymphocytes than nurses without similar exposure¹¹⁾. A recommendation by the U.S. National Institute of Occupational Safety and Health (NIOSH) in 1977 suggested “control of nitrous oxide to a time-weighted average (TWA)

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concentration of 25 ppm during the anesthetic administration period¹¹." In 1989, the American Conference of Governmental Industrial Hygienists (ACGIH) further recommended a N_2O Threshold Limit Value (TLV) of 50 ppm for an 8-hour day¹² and an intermittent exposure level less than 150 ppm during N_2O administration¹³. However, due to its easy and inexpensive application and lack of convenient or efficient monitoring in the workplace, N_2O contamination persisted in anesthetic practices probably throughout the world¹⁴.

Even though employment of active scavenging systems was introduced^{15,16} and accompanied with improvement in anesthetic techniques and instrumentation¹⁷⁻²¹, various anesthetic practices during dental²²⁻²⁴ and veterinary surgeries²⁵ were still demonstrated to generate apparent ambient anesthetic exposure. Variation in manual technique has been claimed contributing to contamination during most adult anesthesia. These include face mask without tubing, poor fitting face mask, inappropriately sealed endotracheal tubing and so on. Some of these have been modified in practices for adult patients in recent years. For example, a mask accompanied with gas-scavenging system²⁶ was demonstrated to diminish N_2O exposure for the anesthesiologists. However, there are some limitations for pediatric anesthesia and much of industrial modification has not been developed for this specific purpose.

This study was aimed to evaluate extensively the sources of N_2O contamination to the anesthetic professionals during routine pediatric anesthesia by employing the Miran 1B2 portable infrared spectrophotometer. Attempts have also been made to understand the extent of N_2O exposure during

various practices of pediatric anesthesia, meanwhile, a modified anesthesia with a local ventilation hood was elucidated for its effectiveness in reducing the pollution. The results evidenced significant N_2O exposure in the breathing zone of the anesthesiologist while conducting pediatric anesthesia and provided caution for professionals working in the operating rooms.

Material and Methods

Several patterns of routine anesthesia in the anesthesiology department of the hospital under investigation were reviewed and five major pediatric general anesthesia were included for evaluation. These included general anesthesia with mask inhalation induction and maintenance (mask general anesthesia), mask induction followed by cuffed-endotracheal intubation, intravenous induction followed by cuffed- or uncuffed-endotracheal intubation, and mask general anesthesia with a modified ventilation hood (Fig. 1). The ventilation hood was a self-designed PVC tent (Fig. 2) which was provided with active suction offering negative pressure inside the tent and providing fresh air from exterior. The hood was fitted from head to upper chest of the patient and was transparent in composition that the anesthesiologists and surgeons can clearly see the patients. At least 6 ($N \geq 6$) real-time whole course measurements were performed for each of the procedures, except in the mask general anesthesia

Fig. 1. Illustration of mask general anesthesia accompanied with a ventilation hood with active suction

The hood covers from the head to the upper chest of the child under anesthesia.

Fig. 2. A ventilation hood made of PVC and fit to the upper chest of the patient was illustrated

The hood carried active suction offering negative pressure inside the tent and providing fresh air from exterior and was transparent in composition that the anesthesiologists and surgeons can clearly see the patients.

with a modified ventilation hood ($N=5$). One senior anesthesiologist was responsible for all the procedures and informed of the monitoring but, however, blinded to the results of measurement throughout the study period.

The breathing zone of the anesthesiologist at sitting position was defined as 1.2 m above ground level and within 30 cm from his or her face while in regular working position (Figs. 1 and 2). The tip of particulate filter on the Miran 1B2 was placed in the respiratory zone of the anesthesiologist

during measurement; i.e., from initial N_2O influx from a low pressure anesthetic machine during induction until patient was removed from operating table. All the measurements were conducted on the first anesthesia or operation in the morning. This was to ensure negligible indoor N_2O left; i.e., less than 0.5 ppm N_2O detection limit by the Miran 1B2. The air exchange rate in all the operating theaters was maintained at 25 times per hour during the study period, as suggested²⁵. All the anesthetic machines have been equipped with the Active Scavenging System (Ohmeda, U.S.A.) with closed reservoir and connected with the anesthetic machine before each data collection.

The measurement was conducted with the Miran 1B2 portable infrared spectrophotometer (Foxboro, Co., U.S.A.; calibrated to manufacturer's specifications) as described²³. Briefly, the spectrophotometer was set to measure infrared absorbance of N_2O at a wavelength of $4.54\ \mu\text{m}$ with a pathlength of 12.75 m at high range. The detection limit was 0.9 ppm, response time each 3 sec and pump flow rate 25–30 l per minute. Before beginning of measurement in each day, Miran 1B2 was calibrated with pure N_2O gas (Scott Medical Product). The results were collected by a data logger and processed by software (Metrosonics Inc.) to acquire time-weighted average concentrations (TWAs) over the monitoring period. The results were presented as the mean TWA and 1 standard deviation for each anesthesia procedure.

Results

The real-time measurement of waste N_2O concentrations around the breathing zone of the anesthesiologist during one pediatric mask general anesthesia was illustrated (Fig. 3). The duration of this procedure was 49 min, including 7.6 min of induction, 33.4 min of maintenance and 8 min of flushing before the patient was removed from the operating table. The TWA for the whole procedure was 84.5 ppm, with TWAs for the induction and flushing periods 306.9 ppm and 104 ppm respectively. Significant fluctuation in N_2O exposure was apparent during different periods of the procedure, particularly during induction and flushing. Peak concentrations of 1,181 and 180 ppm was detected during the induction and flushing periods respectively. Severe contamination was not unusual in other mask general anesthesia practices. The mean TWA in 12 mask general anesthesia and those of another 4 different anesthetic procedures were illustrated in Table 1.

It was evident that procedures with mask general anesthesia, which were the most common pediatric anesthesia

Fig. 3. Real time exposure measurements of N_2O (ppm) in breathing zone of an anesthesiologist during the pediatric mask general anesthesia

Periods of induction, maintenance, flushing and patient leave are indicated (arrow).

in this hospital and other hospitals in Taiwan, generated most N_2O pollution in the breathing zone of the anesthesiologist. The mean TWAs (± 1 S.D.) of N_2O in 12 cases, 85.0 ± 48.4 ppm, significantly increased over the recommended 25 ppm by the NIOSH¹⁾ and 50 ppm by the ACGIH¹²⁾. It was contributed dominantly from N_2O contamination during the periods "induction" and "flushing" and relatively less of the "maintenance," as shown in Table 2. The mean duration of induction and maintenance periods were 4.6 ± 3.2 min and 36.7 ± 3.7 min respectively in these 12 procedures, while the mean TWA concentrations 256.3 ± 144.3 and 51.8 ± 25.1 ppm, respectively. The induction period was relatively short but more polluting than the maintenance periods, while the flushing period was much variable in duration. The induction period carried much higher N_2O exposure that the peak N_2O ranged from 213 to 3,929 ppm in these 12 anesthesia. The mean of these peaks during induction was 1283.3 ± 1278.9 ppm. N_2O of 33 to 329 ppm were noted during flushing periods in these 12 operations, with the mean of these peaks 192.7 ± 95.4 ppm. During common practices, the ratios of N_2O : O_2 supplied (L/min:L/min) were 6:2-3, 2:2 and 2:2 in these three periods respectively.

Mask induction followed by cuffed endotracheal intubation generated N_2O contamination of 33.2 ± 24.0 ppm (TWAs) in 6 separate cases (Table 1). Anesthesia initiated by intravenous induction then replaced with uncuffed endotracheal intubation with caliber smaller than 5.0–6.0 mm in diameter were demonstrated with various degree of N_2O pollution, the mean of TWAs 31.9 ± 18.0 ppm in 6 practices. Intravenous induction followed by cuffed-endotracheal intubation apparently reduced the contamination and the mean of TWAs 11.0 ± 4.7 ppm in 7 practices. Finally, mask general anesthesia accompanied with a ventilation hood with local suction significantly reduced N_2O contamination, the mean of the TWAs 17.9 ± 9.8 ppm in 5 practices.

Discussion

Various general anesthetic procedures for pediatric patients in this study were demonstrated to generate severe N_2O pollution to the anesthesiologist. Among them, mask general anesthesia provided most severe exposure to the anesthesiologist (Table 1). As shown in Figure 3 and Table 2, the induction periods were accompanied with most N_2O

Table 1. The mean time-weighted average N_2O concentrations (TWA) pollution (ppm) to the anesthesiologist in 5 specific anesthesia.

Anesthetic procedure	Numbers of measurement	Mean TWA (ppm) during specific procedures (mean $\pm$ S.D.)
Mask General Anesthesia	12	85.0 ± 48.4
Mask induction followed by cuffed endo-tracheal intubation	6	33.2 ± 24.0
Intravenous induction & uncuffed endotracheal intubation	6	31.9 ± 18.0
Intravenous induction & cuffed endotracheal intubation	7	11.0 ± 4.7
Mask anesthesia with ventilation hood	5	17.9 ± 9.8

Numbers of measurement for each anesthesia were indicated.

Table 2. Mean duration and the N_2O exposure (ppm) to the anesthesiologist during various periods in 12 mask general anesthesia (mean ± 1 S.D.)

Periods	Mean duration	Mean concentration (TWA; ppm)	Extend/mean of peak concentrations (ppm)
Induction	4.6 ± 3.2 min	256.3 ± 144.3	213~3929, 1283.3 ± 1278.9
Maintenance	36.7 ± 3.7 min	51.8 ± 25.1	*
Flushing	*	*	33~329, 192.7 ± 95.4

*: not determined due to great variation.

pollution than the other periods. The induction period during mask general anesthesia spanned approximately 7.6 minutes (15 percent) of the whole specific procedure (Fig. 3) and average 4.6 ± 3.2 min (10 percent) in these 12 anesthesia (Table 2) while it conferred more than half of the total N_2O exposure in one general anesthesia to the anesthesiologist. Even though N_2O administration during induction was relatively short in an 8-hour working day for an anesthesiologist, N_2O exposure was apparently more than the short-term exposure limit of 150 ppm suggested by the ACGIH¹². For an experienced anesthesiologist, more than 5 anesthetic procedures might be routinely expected in one working day. They would also receive more than [TWA 85 ppm in this study $\times$ 5 anesthesia/8 hour-day = TWA 53.1 ppm] that recommended by the NIOSH¹¹.

Several factors contributed to high exposure during the induction periods. First, N_2O was usually employed with relatively higher concentration and mixed with oxygen in the inhalation inlet to the patients ($N_2O:O_2=6L/min:2-3L/min$) during the induction. This was intended to help smooth initial anesthesia for children. Second, the patient was not in complete sedation and it was difficult for the mask to fit these children's faces perfectly while he or she felt discomfort and moved their heads. Moreover, the anesthesiologists usually did not press the mask so tight against children's faces than on adult patients' and allow more N_2O leak to ambient environment. Finally, the mask for children did not fit so well in design than those for adult patients. All these contributed to N_2O leakage from margins of the masks, while mask anesthesia was seldom practiced in current adult anesthesia. Under such situation, the scavenging system usually was not able to diminish the pollution efficiently. If N_2O leakage from masks could be enclosed during the induction period, as modified by the ventilation hood, the anesthesiologist would be much less exposed.

Mask general anesthesia followed by endotracheal cuffed intubation or intravenous induction followed by endotracheal intubation were shown to provide less N_2O exposure. However, N_2O leakage during mask induction before intubation would contribute significantly to the total exposure during the mask general anesthesia followed with cuffed-intubation. The leakage from un-cuffed endotracheal intubation following intravenous induction also generate significant N_2O contamination during the maintenance period, but not during the induction period. In brief, anesthesiologists performing these two procedures would possibly be susceptible to significant N_2O contamination at different periods. Finally, cuffed intubation with intravenous

induction or ventilation hood would significantly diminish the N_2O contamination to the working personnel.

Several other factors would contribute significantly to N_2O contamination during pediatric anesthesia. The size selection of endotracheal tubes were dependent on the age or body size of the patients under anesthesia. If caliber of the tubes were too small for the trachea or the position of tubing was inappropriate, N_2O might leak from the patients' throat, evidenced in the results of intravenous induction followed with uncuffed intubation (Table 1).

The ambient air-exchange rate in the operating rooms would apparently modify N_2O contamination to the anesthesiologists. In this study, the air exchange rate of more than 25 times per hour has been maintained to reduce the waste N_2O gas to negligible between different operations or measurements. However, ambient air exchange was relatively inefficient to reduce N_2O pollution to the anesthesiologist, as they were close to the leakage source from patients.

Miran 1B2 has been demonstrated as a convenient and reliable instrument for detecting trace levels of various waste anesthetics and with minimal interference between different anesthetics. It was shown with satisfactory results while conducting real time measurements in other studies^{22, 23, 25}. The region of measurement, around breathing zone of the anesthesiologist in this study, was not required by the NIOSH¹¹. Measurement around the breathing zone seemed to provide appropriate information of individual exposure. Alternative sites of measurement have been suggested pertinent that when the exposure concentration was less than 35 ppm, the N_2O at the level of anesthetic machine shelf was correlated well with personal sampling^{25, 26}. In this study, the N_2O contamination was most apparent during induction period while the anesthesiologist was close to the patients. Slight underestimation in N_2O exposure by environmental monitoring than by personal sampling was expected. If the measurement was conducted in multiple environmental points around the respiratory zone, this would approximate the results performed by personal monitoring. However, the results provided by convenient Miran environmental measurement would provide practical N_2O exposure level to the anesthesiologist at daily basis. Further studies are suggested to elucidate the difference between this method and those of personal monitoring.

In conclusion, the anesthesiologist was exposed significantly to excessive N_2O during various pediatric anesthesia. In them, mask general anesthesia provided most severe exposure, while mask induction followed with cuffed

endotracheal intubation or intravenous induction followed with uncuffed endotracheal incubation also provided excessive pollution. For the safety of the anesthesiologists, mask anesthesia accompanied with a ventilation hood and active suction is suggested as the alternative for simple mask general anesthesia. Without suitable intervention, the anesthesiologists would be exposed most significantly during mask general anesthesia and appropriate caution or prevention is recommended.

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