# Evaluation of Nitrous Oxide Exposure at a Dental Center

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# Contents



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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

# Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from a manager at a dental center. The request concerned exposures to nitrous oxide during dental procedures. We visited the center in January 2017.

## What We Did

- We observed employees while they administered nitrous oxide during dental procedures.
- We measured nitrous oxide in the air at the dental center.
- We took real-time measurements for nitrous oxide during its administration.
- We asked employees about their work history, nitrous oxide exposure, personal protective equipment, work-related symptoms, and health and safety concerns.
- We looked at drawings of the building's ventilation system and a previous ventilation report.
- We reviewed employee nitrous oxide dosimetry data and dental center incident reports.

We evaluated nitrous oxide exposures at a dental center. Personal exposures occasionally exceeded occupational exposure limits. The ventilation systems were last tested and balanced in 2009 and may not have been supplying enough outdoor air. Employees reported symptoms that could be related to nitrous oxide exposure and were concerned about long-term health effects of nitrous oxide and inadequate ventilation. We recommended evaluating the ventilation systems, having employees trained on the hazards and use of nitrous oxide, and providing patients with various sizes of nasal scavenging masks.

## What We Found

- The ventilation system had not been tested and balanced since 2009, and may not have been providing sufficient outdoor air.
- Personal employee exposures to nitrous oxide ranged from 25 to 200 parts per million, varied from patient to patient, and occasionally exceeded the National Institute for Occupational Safety and Health recommended exposure limit.
- Employees followed most industry best practices in operating and maintaining nitrous oxide equipment and administering nitrous oxide to patients.
- The highest personal exposures to nitrous oxide during dental procedures most likely occurred because of patient mouth-breathing or from poorly fitting nasal scavenging masks.
- Employees reported symptoms that could be related to nitrous oxide exposure.
- Employees were concerned about potential exposure and long-term health effects of nitrous oxide and the need for better ventilation.

## What the Employer Can Do

- Hire a ventilation engineer familiar with healthcare facilities to evaluate, re-test, and re-balance the ventilation system.
- Monitor for nitrous oxide in the air at least yearly.
- Train employees on proper work practices, controls, and hazards associated with nitrous oxide exposure.
- Provide patients with nasal scavenging masks of various sizes.
- Encourage all employees to promptly report work-related health concerns.

## What Employees Can Do

- Learn about nitrous oxide hazards and how to control exposures by using proper work practices.
- Make sure patients know how to properly use the nasal scavenging masks that have been provided.
- Encourage patients to minimize talking and mouth-breathing when nitrous oxide is used in a dental procedure.
- Tell your supervisor about symptoms that you believe are work-related. If symptoms continue, see a healthcare provider who is knowledgeable in occupational medicine.

# Abbreviations

| | |
|---|---|
| ACGIH® | American Conference of Governmental Industrial Hygienists |
| ACH | Air changes per hour |
| CFR | Code of Federal Regulations |
| HVAC | Heating, ventilation, and air-conditioning |
| NIOSH | National Institute for Occupational Safety and Health |
| $N_2O$ | Nitrous oxide |
| OEL | Occupational exposure limit |
| OSHA | Occupational Safety and Health Administration |
| PPE | Personal protective equipment |
| ppm | Parts per million |
| REL | Recommended exposure limit |
| TLV® | Threshold limit value |
| TWA | Time-weighted average |

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# Introduction

The National Institute for Occupational Safety and Health (NIOSH) Health Hazard Evaluation Program received a request from a manager at a dental center (center). The request concerned exposures to nitrous oxide ($N_2O$) during dental procedures. In January 2017 we toured the center, evaluated employee exposures to $N_2O$, spoke with managers and employees, and observed workplace processes and practices and workplace conditions. We provided our preliminary recommendations in a letter to the employer and the employee representative in January 2017.

The center staff included dental assistants, dental hygienists, dental residents, and dentists and nonclinical personnel (e.g., front desk, coordinator, and interpreter). It was one of four local centers owned and operated by the same health system. The dental residents and dentists administered $N_2O$ to patients for dental restorations (filling cavities) and tooth extractions. Procedures requiring $N_2O$ were mainly scheduled on Monday mornings in 30-minute blocks but the clinic was open Monday through Friday. Some of the clinical staff rotated between centers.

## Workplace Description

At the time of this evaluation, the center had seven dental operatories, referred to as OP 1–7. The center also had a lab, sterilization room, supply room, front office, and a dark room. In addition to the standard dentistry equipment located in all of the dental operatories, OP-2 and OP-3 had an Accutron® $N_2O$ conscious sedation system. The OP-3 operatory was an enclosed room with a door that could be shut if the patient needed more privacy, whereas OP-2 was open to the other exam rooms and did not have a door. Each Accutron system contained two cylinders of oxygen and two cylinders of $N_2O$ and a vacuum scavenging system that exhausted the $N_2O$ to the roof. On the day of our visit, one dentist administered $N_2O$, and two dental assistants assisted in the procedures.

# Methods

Our objectives included:

- evaluating sources of $N_2O$ exposures (ill-fitting masks, patient mouth-breathing, problems with the scavenger system, and/or leaks in the $N_2O$ delivery system);
- determining whether employees were experiencing symptoms associated with $N_2O$ exposure;
- determining employees' health and safety concerns; and
- investigating whether employees were being exposed to $N_2O$ above applicable occupational exposure limits (OEL) during administration of $N_2O$ in the dental operatories.

## Workplace Observations

We observed the work practices of two dental assistants and one dentist during the administration of $N_2O$ for four dental procedures on pediatric patients. We also met with the building engineer to discuss the $N_2O$ scavenging system and the building's heating, ventilation, and air-conditioning (HVAC) system.

## Record Review

We reviewed past employee $N_2O$ dosimetry data for the center we visited as well as $N_2O$ data from two other centers that were part of the same health system. We reviewed the Unusual Event and Incident Report Forms for the period covering 2015–2016 from two of the centers for which we had data. We also reviewed a 2009 testing and balancing report for the commissioning of the HVAC system for the center that we visited.

## Exposure Assessment

We collected personal air samples for $N_2O$ using Vapor-Trak® passive dosimeter badges. The badge manufacturer analyzed them according to a modified Occupational Safety and Health Administration (OSHA) Method ID-166. We analyzed five full-shift personal air samples and three short-term (approximately 5 hour) personal air samples. The short-term air samples were collected on two dental assistants and one dentist only during the time of $N_2O$ administration. We also evaluated $N_2O$ exposure using a calibrated Miran® Sapphire $N_2O$ direct-reading monitor on 1 day during four dental procedures, two in each dental operatory room.

## Employee Medical Interviews

We obtained a list of all employees working in the center and interviewed those that were present during our visit confidentially. We asked employees about their work history, $N_2O$ exposure, use of personal protective equipment (PPE), work-related symptoms, and health and safety concerns.

# Results and Discussion

## Workplace Observations

We observed that dental assistants thoroughly evaluated the $N_2O$ equipment prior to its use and reviewed the standard operating procedure for the daily and monthly system checks. The daily checks included testing the fail-safe system to make sure that $N_2O$ did not flow unless oxygen was also flowing at the same time. In addition, the dental assistants checked all hose and mask connections and gas cylinder volumes. Monthly checks by the dental assistants included a $N_2O$ and oxygen knob calibration test, an oxygen flush valve test, an out-spot check valve test (verifying that $N_2O$ was reaching the patient's mask), and an override air valve test.

The managers reported that the center's mechanical engineer performed a bubble-leak test of the Accutron scavenging system every quarter, and yearly checks as recommended by the manufacturers. Every time the $N_2O$ cylinder was changed, the dental assistants replaced the O-rings and visually inspected all $N_2O$ equipment for worn parts, cracks, holes, or tears. We observed that the nasal scavenging mask (Figure 1) was secured on each of the patients' nose prior to starting $N_2O$ administration. The nasal scavenging mask was scented and patients were permitted to select their scents, but all nasal scavenging masks were the same size. All components of the nasal scavenging mask were single use. The clear plastic on the outside of the nasal scavenging mask was designed so that condensation from patient's exhaled breath would be visible on the interior of the mask, a visual check to ensure patients breathed through their nose. In addition, 100% oxygen was administered for approximately 5 minutes before and 5 minutes after $N_2O$ administration. Finally, the concentration of $N_2O$ never exceeded 35% during the procedures that we observed, the highest $N_2O$ concentration permitted by the center's protocol. These practices were consistent with recommendations from the American Dental Association for the "best practices for $N_2O$ use" [ADA 2017].

Figure 1. Patient nasal scavenging masks in multiple colors containing different scents.
Photo by NIOSH.

The scavenging system (Figure 2) supplied oxygen and $N_2O$ at a selected rate that could be monitored by a gauge on front of the equipment. NIOSH recommends that scavenging systems maintain a scavenging flow rate of at least 45 liters per minute at each nasal scavenging mask and exhaust outside of the building away from outdoor air intakes, windows, or walkways [NIOSH 1994]. We observed a flowmeter that indicated that the vacuum exhaust rate was approximately 45 liters per minute at the nasal scavenging mask and was always on when $N_2O$ was being used. In addition, the scavenging system exhausted to the roof, approximately 30 feet from the outdoor air intakes.

At this center, most of the patients receiving $N_2O$ were children. Boiano et al. [2016] found the use of exposure control practices varied by type of patient (adult or pediatric) and anesthesia care providers. In the Boiano et al. study, there was lower adherence to proper exposure control practices by anesthesia care providers who administered $N_2O$ to pediatric patients than to adult patients.

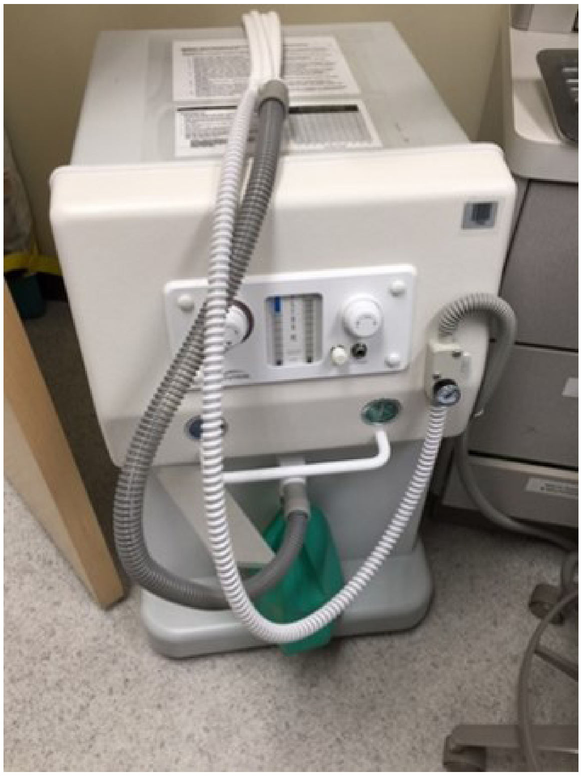

Figure 2. Accutron $N_2O$ administration and scavenging system. Photo by NIOSH.

## Record Review

Between December 2015 and our visit in January 2017, the center that we evaluated had collected $N_2O$ dosimetry data on two dentists over 10 days and on two dental assistants over 1 day. Results showed that concentrations ranged from 21.4 parts per million (ppm) to 500 ppm, averaged over the duration of $N_2O$ administration. The $N_2O$ exposure measurements were above the NIOSH recommended exposure limit (REL) of 25 ppm, as a time-weighted average (TWA) over the duration of the procedure, for 8 of the 10 measurements on dentists and on both measurements on the dental assistants. Full-shift TWA $N_2O$ concentrations ranged from 8.8 ppm to 259 ppm. Both of the dentists, but neither dental assistant, had full-shift $N_2O$ exposures above the American Conference of Governmental Industrial Hygienists (ACGIH®) threshold limit value (TLV) of 50 ppm, as a TWA over the duration of the work shift.

A second center in the health system had evaluated dentists' $N_2O$ exposures on three occasions, with two of the three sampling results exceeding the NIOSH REL and one of the three results exceeding the ACGIH TLV. Concentrations ranged from 19 ppm to 143 ppm, averaged over the duration of $N_2O$ administration. Full-shift TWA exposure concentrations ranged from not detected to 98.6 ppm. The third center evaluated dentists' $N_2O$ exposures on six occasions, exceeding the NIOSH REL five of the six times, but never exceeding the ACGIH TLV. Concentrations ranged from 11.3 ppm to 296 ppm, averaged over the duration of $N_2O$ administration and from 2.1 ppm to 17 ppm as a full-shift TWA.

The two centers with the majority of $N_2O$ overexposures, including the center we visited, documented them in an incident report dated 2015–2016. The incident report identified mouth-breathing and crying by pediatric patients as factors contributing to $N_2O$ overexposures to personnel. In response to these $N_2O$ overexposures the center's director/safety officer (1) checked the $N_2O$ scavenging equipment at both centers to ensure proper function, (2) asked dental personnel for information concerning all safety checks and volume of $N_2O$ used, and (3) placed personal $N_2O$ dosimeters on dental assistants at the center we evaluated. Additionally, a specialist familiar with the Accutron scavenging system inspected the $N_2O$ equipment at this center and found them working properly. The incident report noted that the equipment specialist believed the employees' exposures were due to being close to the pediatric patients' exhaled breath. The report also noted that the center air was changed a minimum of 6 times per hour and outdoor air was continuously being introduced.

According to the 2009 test and balance report, the center we evaluated had two constant volume HVAC systems, one that supplied air to the halls and offices (HPU-4A) and another that supplied air to the perimeter, including the dental operatories (HPU-5A). According to the report, both systems recirculated air and the HPU-5A air handler supplied 9.2% outdoor air. However, because this HVAC system was tested in 2009 the reported percentage of outdoor air may not accurately reflect the system's current performance.

Ventilation guidelines established for treatment rooms and operating rooms in healthcare facilities are described in Appendix A. Table 1 compares our estimated air changes per hour (ACH) calculated using the center's 2009 test and balance report to minimum ACH recommendations for procedure rooms and operating rooms. OP-2 and OP-3 were below the recommended 2 ACH for outdoor air for procedure rooms and well below the recommended 4 outdoor ACH for operating rooms [AIA 2014; ANSI/ASHRAE 2013]. Although we did not evaluate room pressurization, NIOSH recommends maintaining dental operatory rooms under negative air pressure relative to surrounding areas, meaning that air flows into the operating room from adjacent areas. NIOSH also recommends, where possible, using 100% outdoor air for dental operatory ventilation and locating air exhausts in the operating room at floor level because $N_2O$ is heavier than air [NIOSH 1996]. The air exhausts in OP-2 and OP-3 were located at the ceiling level.

Table 1. Calculated room ventilation rates for OP-2 and OP-3

| Room | Total ACH | Outdoor ACH |
|---|---|---|
| OP-2 | 10 | 1 |
| OP-3 | 9 | 1 |
| Recommended minimum airflow for procedure rooms* | 6 | 2 |
| Recommended minimum air flow for operating room† | 20 | 4 |

*Per ANSI/ASHRAE 2013; AIA 2014, a room used for procedures involving $N_2O$ that contains provision for exhausting anesthetic waste gases.
†Per ANSI/ASHRAE 2013; AIA 2014, a room used for minor or major surgical procedures performed with a patient under analgesic or dissociative drugs.

## Area Air Sampling for Nitrous Oxide

We used a direct-reading monitor to measure $N_2O$ in OP-3 during a procedure involving a pediatric patient (Appendix B, Figure B1). The y-axis of the graph ranged from 0 ppm to 90 ppm. The $N_2O$ monitor was on the side of the patient where the dentist was standing. This was the second pediatric patient to receive $N_2O$ in the room on the morning of monitoring. The $N_2O$ concentration in the room averaged 25 ppm for approximately 30 minutes between patients. The second patient appeared to have a well-fitting nasal scavenging mask, and we saw condensation inside the nasal cone of the scavenger, indicating that the patient was breathing mainly through the nose. The $N_2O$ concentrations increased when we moved the monitor within 2 feet of the patient's mouth and to the dentist's shoulder. This is likely due to patient mouth-breathing during the procedure. During the procedure $N_2O$ levels at the dentist's shoulder averaged 41 ppm and ranged from 18 ppm to 85 ppm. After the flow of $N_2O$ was turned off and the mask removed, levels in this same area ranged from 36 ppm to 72 ppm with a 10-minute average concentration of 53 ppm. We suspect that $N_2O$ levels lingered in OP-3 due to poor air mixing and exhausting of the room.

Appendix B, Figure B2 shows the area $N_2O$ concentration in OP-3 in the early afternoon with no patients present. The y-axis of the graph ranged from 0 ppm to 20 ppm. Nitrous oxide administration had ended at 11:17 a.m. in this room and at 12:00 p.m. in the adjacent OP-2. The $N_2O$ concentration near the door leading from OP-3 to the hallway increased from 6.2 ppm to 11 ppm from 1:13 p.m. to 1:24 p.m. This increase was likely due to $N_2O$ migrating into the hall, suggesting that OP-3 was under positive air pressure relative to the hallway. At 1:25 p.m., we moved the monitor to the opposite side of the room near a closed window. At this location the $N_2O$ concentrations ranged from 16 ppm to 19 ppm until about 1:30 p.m. and then decreased rapidly (over approximately 2 minutes) to about 5.0 ppm, and continued decreasing more slowly (over approximately 1 hour) to about 2.0 ppm at 2:35 p.m. At that time the batteries on the monitor ran out, and we were not able to take additional measurements. Levels of $N_2O$ near the window may have remained higher than other locations in the room because of the room design and poor air mixing. The fact that $N_2O$ levels were around 2 ppm more than 2.5 hours after anesthetic gas was last used suggests that ventilation in the room could be improved. For example, the ceiling mounted return and supply air grilles were a few feet from each other, a design that could result in short-circuiting and poor air mixing in the room.

We also measured the $N_2O$ concentration in OP-2 during administration to a pediatric patient (Appendix B, Figure B3). The y-axis ranges from 0 ppm to 250 ppm. During the procedure, the patient wiggled and breathed out through the mouth despite reminders from the dental assistant to remain still and breathe through the nose. In addition, the patient had a small face that could have made achieving a good fit with the scavenging mask difficult. The background $N_2O$ concentration in the room was 21 ppm because of a previous procedure approximately 30 minutes prior. During the procedure, the $N_2O$ concentration averaged 120 ppm at the dentist's shoulder, with a maximum of 200 ppm, likely due to the patient's mouth-breathing and a poorly fitting mask. When the procedure ended the $N_2O$ concentration in this room decreased to 2.0 ppm after 40 minutes. This more rapid decline in $N_2O$ levels compared to OP-3 may be due to better ventilation. For example, OP-2 was an open area compared to OP-3 and therefore may have benefited from general dilution ventilation.

## Personal Air Sampling for Nitrous Oxide

None of the personal samples we collected with passive dosimeter badges had detectable concentrations of $N_2O$. This was an unexpected result. We contacted the dosimeter manufacturer to determine if we used the samplers correctly (we did), and if there were any errors in the analysis of the samples (there were none). Additionally, the manufacturer's quality control and assurance department could not identify any problems in the storage or performance of these dosimeters.

Despite the fact that $N_2O$ was not found in the personal air samples that we collected, our area air sampling did measure of $N_2O$ in breathing-zone of staff during dental procedures. We also measured $N_2O$ in the general room air of OP-2 and OP-3 before, during, and after dental procedures.

The primary route of exposure to employees working with $N_2O$ is inhalation. If the $N_2O$ delivery or exhaust systems have no leaks, the $N_2O$ exposures to the dental staff will typically occur from patient mouth-breathing or from leaks around the nasal scavenging mask [NIOSH 1994]. Nitrous oxide concentrations can vary according to the amount of outdoor air supplied to the dental operatories [NIOSH 1990]. Other factors that may contribute to high concentrations of $N_2O$ include delivery flow rates, patient cooperation, and improper techniques for administering the $N_2O$. Employees at this center used appropriate $N_2O$ delivery rates and followed industry best work practices.

Occupational exposure to $N_2O$ in dental clinics that administer $N_2O$ has been documented in previous studies. Gilchrist et al. [2007] evaluated 8-hour TWA exposures of dentists working in a pediatric dental unit that used active scavenging equipment. The dentists' TWA exposures ranged from 16 ppm to 374 ppm, with a mean of 151 ppm. A research study evaluating two different types of scavenging systems found that neither was able to control occupational exposures to below the NIOSH REL of 25 ppm over the duration of exposure [Rademaker et al. 2009]. Using passive dosimetry, Boyer [1992] examined the $N_2O$ exposure of dental assistants, dentists, and staff who did not administer $N_2O$, such as dental hygienists, in a dental clinic with scavenging equipment. Results indicated that even with scavenging equipment, exposures above the NIOSH REL of 25 ppm commonly occurred [Micklesen

1993; NIOSH 1990]. Crouch and Johnston [1996] determined that mask leakage due to poor fit was the primary cause of $N_2O$ emissions, and that an exhaust system placed on the chin, chest, or in the mouth proved effective in capturing mouth emissions. Crouch et al. [2000] determined that patient mouth-breathing, talking, and crying also released $N_2O$ into the air, and that the typical scavenging system did not control emissions from the patient's mouth, so an auxiliary local exhaust system may be needed to control those emissions.

## Employee Medical Interviews

We held confidential medical interviews with all 14 employees (11 clinical and 3 nonclinical staff) who were present at the center we visited. At the time of our visit, there were 39 employees across all centers; some employees rotated between centers. Dental residents' and dentists' primary duties included dental restorations and tooth extractions. Some of the dental residents and dentists also administered $N_2O$ during dental procedures. Dental hygienists' primary duties were routine cleanings such as removing plaque from patients' teeth and limited patient exams. On rare occasions, the dental hygienists assisted the dentist with $N_2O$ procedures. Dental assistants' primary duties included setting up and cleaning the dental operatories (e.g., preparing dental tools, disinfecting the room, sterilizing equipment using ultrasonic cleaning and autoclave heating), taking dental x-rays, and assisting the dentist during dental procedures. Many of the dental assistants also assisted the dentists with $N_2O$ procedures. The administrative duties of nonclinical staff (front desk, coordinator, and interpreter) included scheduling, recordkeeping, and translating/interpreting. Employees reported working at the center an average of 3.5 years (range: 3 days–15 years. Twelve employees had worked at another center or dental school an average of 9 years. Employees' average age was 40 years (range: 21–53), and 13 of 14 employees were female.

Employees were asked to respond "yes" or "no" to a question regarding exposure to $N_2O$. Ten employees reported having worked with $N_2O$ and/or other inhalational anesthetic agents for an average of 7 years including dental training years. These employees usually worked an average of 5 hours per week with $N_2O$ and this depended on the scheduled procedures for the week; 75% of their time was spent in direct patient care activities. Two employees reported ever having worn a personal $N_2O$ dosimeter monitoring badge. Both reported they were given their results with a noted overexposure to $N_2O$.

When we asked employees who had rotated between centers and worked with inhalational anesthetic agents about differences between the centers, most employees reported that the $N_2O$ equipment, best practices, and procedures had been consistent among the centers. Two employees reported that one center was smaller.

Most of the employees working with $N_2O$ reported wearing eye protection (safety glasses), nitrile gloves, and a surgical mask or face shield during $N_2O$ procedures. All employees reported always using scavenging equipment for $N_2O$ procedures. All employees also reported inspecting and testing for leaks of the scavenging equipment (e.g., mask, hose) in the dental operatories. One employee reported that the dentist always placed the nasal scavenging mask on the patient, and another employee reported the dentist always started the flow of $N_2O$. In addition, all employees reported always following safe work practices while working with $N_2O$ including:

- ensuring proper nasal scavenging mask fit (size, straps tightened and snug to patient's face),
- minimizing mouth-breathing of patient (discouraging patients from talking and breathing through mouth),
- checking reservoir bag for proper inflation,
- turning on 100% oxygen before starting $N_2O$ gas flow,
- turning off $N_2O$ gas flow before removing patient's mask while keeping 100% oxygen flow, and
- turning on vacuuming exhaust before $N_2O$ delivery.

All but one employee who worked with $N_2O$ reported they attended employer-provided annual in-service training or other onsite or offsite educational sessions specifically about $N_2O$ exposure. Employees received training on the potential hazards associated with $N_2O$ exposure and received training to recognize the health effects associated with $N_2O$ exposure. This in-service training also included a component on how to determine if the patient mask had been put on properly.

One of the 14 employees reported an unexplained fertility problem. Two employees reported miscarriages within the last 2 years. One other employee reported a miscarriage several years ago while not working at this center. Regarding fertility effects of $N_2O$ exposure, most studies have occurred in animals. They have not been found to occur at lower than 1,000 ppm of exposure [Holson et al. 1995]. There is evidence that $N_2O$ can induce fetotoxicity and fertility defects through inhibition of a specific enzyme, methionine synthase, but there is no evidence that this toxicity occurs with concentrations below established OELs. The animal data suggests that doses of 500 ppm are a threshold for this toxicity (i.e., 10 times the United States' OELs). Most of the occupational exposure studies regarding anesthetic waste gases were performed in the prescavenging era in operating rooms [Sanders et al. 2008]. In this center, employees reported always using scavenging equipment and followed safe work practices to reduce their $N_2O$ exposure. Regarding the relationship of $N_2O$ and reproductive problems, there have been very few scientific studies to examine this relationship, and the studies are at least 20 years old. Two studies by Rowland and colleagues [1992, 1995] using information obtained by questionnaires of 4,856 female dental assistants found no increase in miscarriages or spontaneous abortion or problems with fertility in women working in offices with scavenging equipment. In offices without scavenging systems, there were reduced fertility rates for those who worked with $N_2O$ for more than 3 hours and increased miscarriages and spontaneous abortions for those who worked with it for 5 or more hours [Rowland et al. 1992, 1995]. In those studies, the exposure concentrations were poorly defined and the dose-response relationship (i.e., whether increasing concentration of $N_2O$ was related to more reproductive problems) was difficult to identify because of self-reported exposures. A study by Sanders and colleagues [2008], mentioned that data was needed from well-conducted prospective studies with quantified $N_2O$ exposure levels and appropriate control groups to better answer the question of reproductive toxicity. More information regarding $N_2O$ exposure can be found in Appendix A.

Eight employees reported dizziness, lightheadedness, headache, fatigue, or nausea while at work in the last 6 months. Some of those employees reported their symptoms were most prominent on busy days after $N_2O$ procedures in OP-3. Lightheadedness, eye and upper airway irritation, cough and shortness of breath have been associated with acute exposure to $N_2O$ [New Jersey Department of Health and Senior Services 2004]. Excessive exposure may also cause headache, nausea, fatigue, and irritability [Pohanish 2012]. It has also been suggested that mood factors like sleepiness or mental tiredness may increase following $N_2O$ exposures to as low as 50 ppm [Venables et al. 1983]. Because many of these symptoms are common and may be due to other causes, it is important for those who continue to experience them be evaluated by an occupational medicine physician to determine work-relatedness.

Two employees reported an odor during $N_2O$ procedures (e.g., at the first start of the flow of $N_2O$ or when working close to the patient's exhaled breath) in the last 6 months. According to the safety data sheet for $N_2O$, it is a colorless gas with a sweet odor. Three employees reported irritation of eyes, nose, or throat in the last 6 months; these three employees also reported a history of seasonal allergies (allergic rhinitis). Nitrous oxide does not cause allergic symptoms similar to those of seasonal allergies, although it rarely causes throat dryness and chest discomfort when given in doses to give analgesia.

We asked employees a final open-ended question regarding what, if any, health or safety concerns they had about their work. Nine employees reported at least one health and/or safety concern. The health concerns reported by five employees included potential long-term health effects of $N_2O$, infertility, throat irritation after administration of $N_2O$ in OP-3, musculoskeletal symptoms related to shoulder and neck, or they did not know the procedures concerning to whom they should report health concerns. Safety concerns reported by six employees included potential exposure to $N_2O$ and high $N_2O$ dosimeter readings, duration of a dental procedure using $N_2O$, and the need for better ventilation, especially in OP-3.

# Conclusions

Our review of personal exposure data collected by the center and our area air samples showed that staff were often exposed to $N_2O$ above the NIOSH REL and/or ACGIH TLV. The exposures were likely from patient mouth-breathing during dental procedures and poorly fitting nasal scavenging masks. We observed employees following dental industry best practices to reduce $N_2O$ exposure, including the use of scavenging equipment, which has been shown to reduce employee exposure. Certain employees had specific symptoms consistent with $N_2O$ exposure, especially after busy days of $N_2O$ procedures. Some employees had concerns about potential reproductive health effects of $N_2O$ exposure. Deriving conclusions about reproductive effects is hampered by the fact that there are no prospective epidemiologic studies with quantified $N_2O$ exposure levels. Until then, and the reproductive issues are settled, it is prudent to ensure that exposure levels do not exceed the NIOSH REL. The general area ventilation system had not been tested and balanced since its commissioning in 2009. Testing and balancing the ventilation system, providing more outdoor air, providing the patients with multiple mask sizes to properly fit their faces, and continuing to follow the dental industry best practices will help in reducing exposures.

# Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the dental center to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the dental center.

Our recommendations are based on an approach known as the hierarchy of controls (Appendix A). This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and PPE may be needed.

## Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. Hire a ventilation engineer familiar with healthcare facilities to evaluate the HVAC systems so that the dental operatories have adequate ventilation and that potentially contaminated air from the dental operatories is not recirculated to other portions of the facility. Specific ventilation recommendations include the following:
    a. Use supply register louvers in the ceilings that direct outdoor supply air toward the dental chair. This will maximize the ability to provide mixing and dilution of the air in the dental operatory. Exhaust air vents should be placed at or near the floor.
    b. Exhaust contaminated air directly outdoors away from windows, doors, and HVAC air intakes. The recirculation of dental operatory air is not recommended.
    c. Maintain a negative air pressure in the dental operatories relative to surrounding areas, meaning that air flows from surrounding areas and into the dental operatory. This will help minimize $N_2O$-containing air from migrating into surrounding areas.
    d. Offer patients a choice in nasal scavenging mask sizes to assure proper fit for various sized faces.
2. Install secondary local exhaust ventilation if the previous recommendations do not lower the $N_2O$ levels below the OELs.

## Administrative Controls

The term administrative controls refers to employer-dictated work practices and policieto reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Encourage dental personnel to use work practices that lower exposure to $N_2O$ including limiting the duration of $N_2O$ as much as possible, using the lowest flow rate of $N_2O$, slowly increasing the level of $N_2O$ (if needed), and maintaining the farthest distance possible from patients' mouths.
2. Periodically evaluate employee exposures to $N_2O$ during anesthetic administration.
    a. Measure short-term (during administration of $N_2O$) and full-shift exposures.
    b. Monitor $N_2O$ exposure of all dental personnel who work with $N_2O$.
    c. Resample $N_2O$ exposure after implementing any change to assure that it was effective (i.e., providing multiple nasal scavenging mask sizes, adjusting the ventilation system, and/or adding a local exhaust ventilation system).
3. Ensure that all dental personnel involved in $N_2O$ procedures are trained on potential hazards. Such training includes recognizing the health effects associated with exposures to $N_2O$ and training on proper work practices and use of engineering controls to reduce $N_2O$ concentrations.
4. Encourage employees to report potential work-related health and safety concerns to their supervisors. Employees with persistent symptoms such as lightheadedness, headache, nausea, fatigue, irritability, eye and upper airway irritation, cough, or shortness of breath should promptly seek medical attention from a healthcare provider who is knowledgeable in occupational medicine.

# Appendix A: Occupational Exposure Limits and Health Effects

NIOSH investigators refer to mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a pre-existing medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a time- weighted average (TWA) exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limit or ceiling values. Unless otherwise noted, the short-term exposure limit is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- The U.S. Department of Labor OSHA permissible exposure limits (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH RELs are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2010]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, PPE, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Other OELs commonly used and cited in the United States include the TLVs, which are recommended by ACGIH, a professional organization. The TLVs are developed by committee members of this association from a review of the published, peer-reviewed literature. These OELs are not consensus standards. TLVs are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2017].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/GESTIS/GESTIS-Internationale-Grenzwerte-für-chemische-Substanzen-limit-values-for-chemical-agents/index-2.jsp, contains international limits for more than 2,000 hazardous substances and is updated periodically.

OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Sa
ety and Health Act o 1970 (Public Law 91–596, sec. 5(a)(1))]. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions. NIOSH investigators also encourage use of the hierarchy of controls approach to eliminate or minimize workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) PPE (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health. Control banding focuses on how broad categories of risk should be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement existing OELs.

# Nitrous Oxide

The anesthetic gas $N_2O$ has been used since 1844, often in conjunction with other anesthetic gases [ACGIH 2001]. Wilson and Gosnell [2016] concluded that since 1996 more practitioners are using $N_2O$ and an increased perception that more pediatric patients need $N_2O$.

OSHA has not established a permissible exposure limit for $N_2O$. The NIOSH REL is 25 ppm averaged over the duration of anesthetic administration. The NIOSH REL is based on a report of decrements in audiovisual tasks following exposure at 50 ppm and is intended to prevent decreases in mental performance, audiovisual ability, and manual dexterity during exposures to $N_2O$ [NIOSH 1977, 1994]. Since then concern for reproductive effects such as reduced fertility; spontaneous abortion; and neurological, renal, and liver disease has led NIOSH to recommend minimizing employee exposures [NIOSH 1994]. ACGIH recommends an 8-hour TLV-TWA of 50 ppm [ACGIH 2017], a limit based on preventing embryo-fetal toxicity in humans and significant decrements in human cognitive functions.

Measures for controlling exposures to $N_2O$ in dental operatories include effective scavenging devices, proper equipment, maintenance and routine leak checks of the $N_2O$ delivery system, and safe work practices on the part of the dental assistants and dentists. In a recent NIOSH survey of dentists, dental hygienists, and dental assistants, the authors concluded that adherence to recommended health and safety practices during dental procedures was lacking. The authors of that study also concluded that proper management of $N_2O$ should include properly fitted nasal scavenging masks, supplementary local exhaust ventilation when $N_2O$ cannot be controlled alone with nasal masks, adequate general ventilation, regular inspection of $N_2O$ delivery and scavenging equipment for leaks, standard procedures to minimize exposure, periodic training, ambient air and exposure monitoring, and medical surveillance [Boiano et al. 2017].

Scavenging systems to control $N_2O$ at the point of use is the preferred method. A common scavenging system design is the "mask within a mask" unit, with tubes supplying oxygen and $N_2O$ to the inside of the interior mask, and two tubes ventilating the space between the two masks where the patient exhales. The recommended flow rate for this type of system is 45 liters per minute [NIOSH 1977].

These types of scavenging systems, while shown effective in reducing anesthetic gas exposure, do not consistently reduce $N_2O$ to concentrations below the NIOSH REL of 25 ppm [NIOSH 1990]. Additional auxiliary ventilation has shown mixed results [Micklesen 1993]. Proper ventilation of dental operatories is important because of the types of surgical procedures performed and the anesthetic gases used in them. Therefore, appropriate ventilation design criteria should be considered. These criteria include the *Guidelines for Design and Construction of Health Care Facilities* published by the Facility Guidelines Institute and the Health Care Facilities chapter of the *ASHRAE Handbook: HVAC Applications* [ASHRAE 2015; FGI 2014]. When anesthetic gases are used and surgical procedures occur, the most appropriate ventilation criteria in these guidelines are those identified for "operating rooms." For less invasive procedures performed without anesthetic gases, the criteria identified for "treatment rooms" are most appropriate. In Facility Guidelines Institute and the Health Care Facilities, Table 2.1-2 shows a minimum ventilation requirement of 6 ACH of total ventilation (outdoor air plus recirculated air) for treatment rooms and a minimum ventilation requirement of 15 ACH for "operating/surgical cystoscopic rooms" with a minimum of 3 ACH of outdoor air [FGI 2014]. ASHRAE's *HVAC Applications Handbook* includes a similar table (Table 3) of ventilation requirements. The ASHRAE recommendation in this table for treatment rooms is also 6 ACH of total ventilation. However, ASHRAE also stipulates a minimum of 2 ACH of outdoor air. The ASHRAE recommendations for operating rooms (recirculating HVAC design) are a minimum of 20 ACH of total ventilation with a minimum of 4 ACH of outdoor air [ASHRAE 2013]. The AIA and ASHRAE design criteria state that a separate air exhaust system or a scavenging system is required when anesthetic gases are used [AIA 2014; ASHRAE 2015]. ANSI/ASHRAE also publishes *Standard 62: Ventilation for Acceptable Indoor Air Quality*, which provides guidelines on suitable outdoor air requirements for ventilation rates in healthcare facilities. Current and past versions of this standard indicate requirements of 15 cubic feet per minute of outdoor air per person for medical procedure rooms of healthcare facilities and 30 cubic feet per minute of outdoor air per person for operating rooms [ANSI/ASHRAE 2016].

# Appendix B: Figures

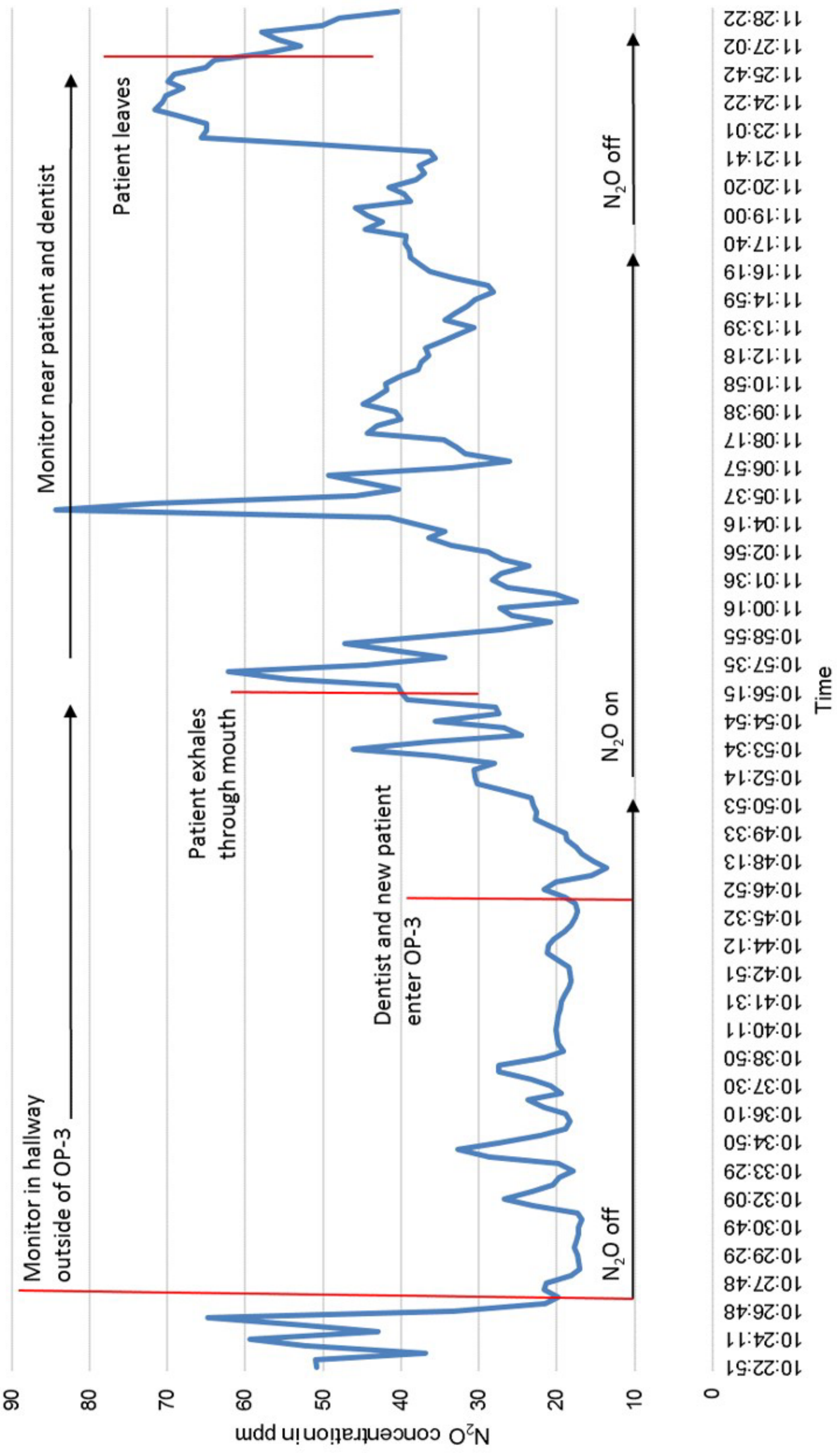


Figure B1. Time history graph showing $N_2O$ concentrations during administration in OP-3, dentist side of the patient.

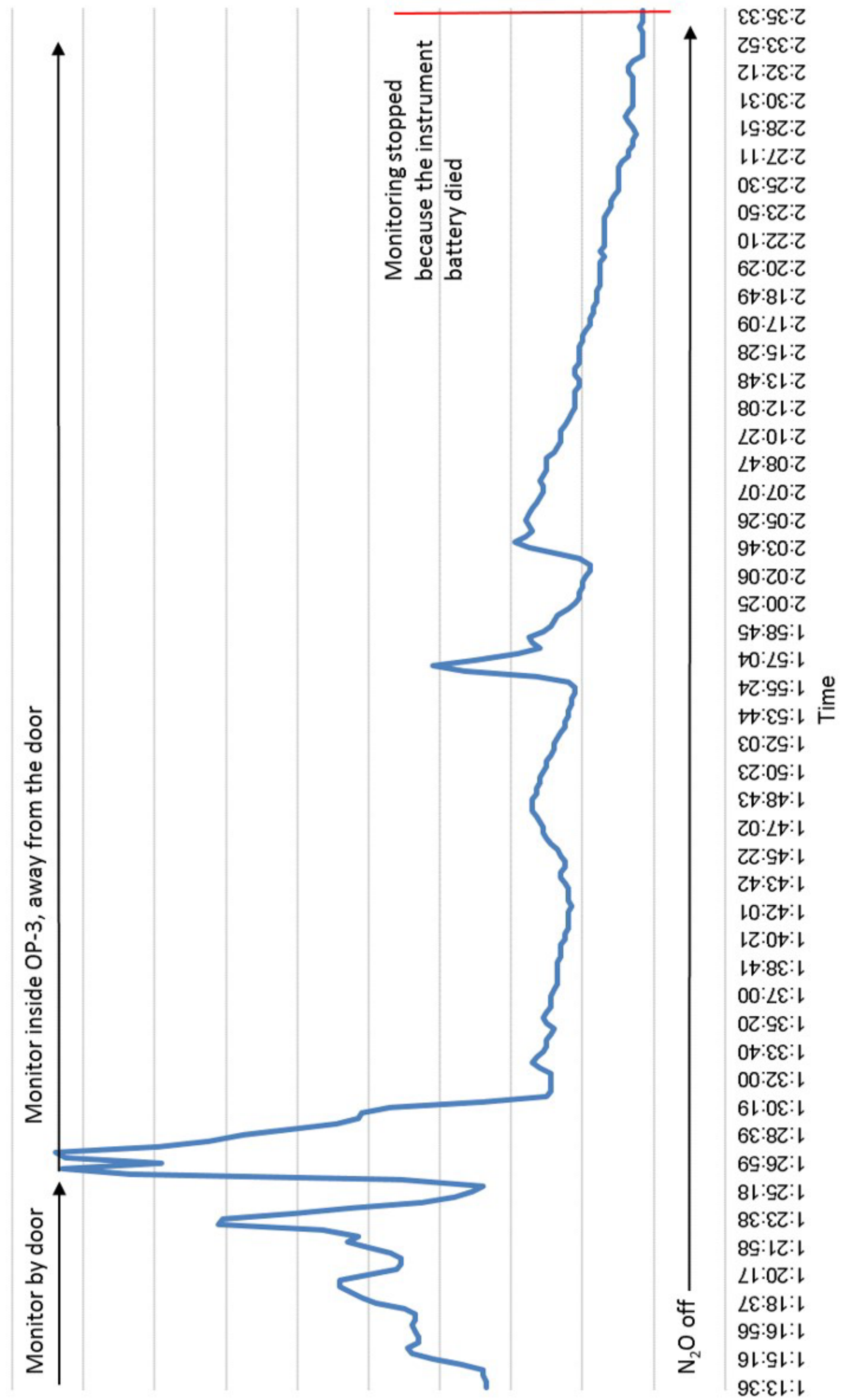


Figure B2. Time history graph showing $N_2O$ concentrations in OP-3 after administration of $N_2O$ had ended.

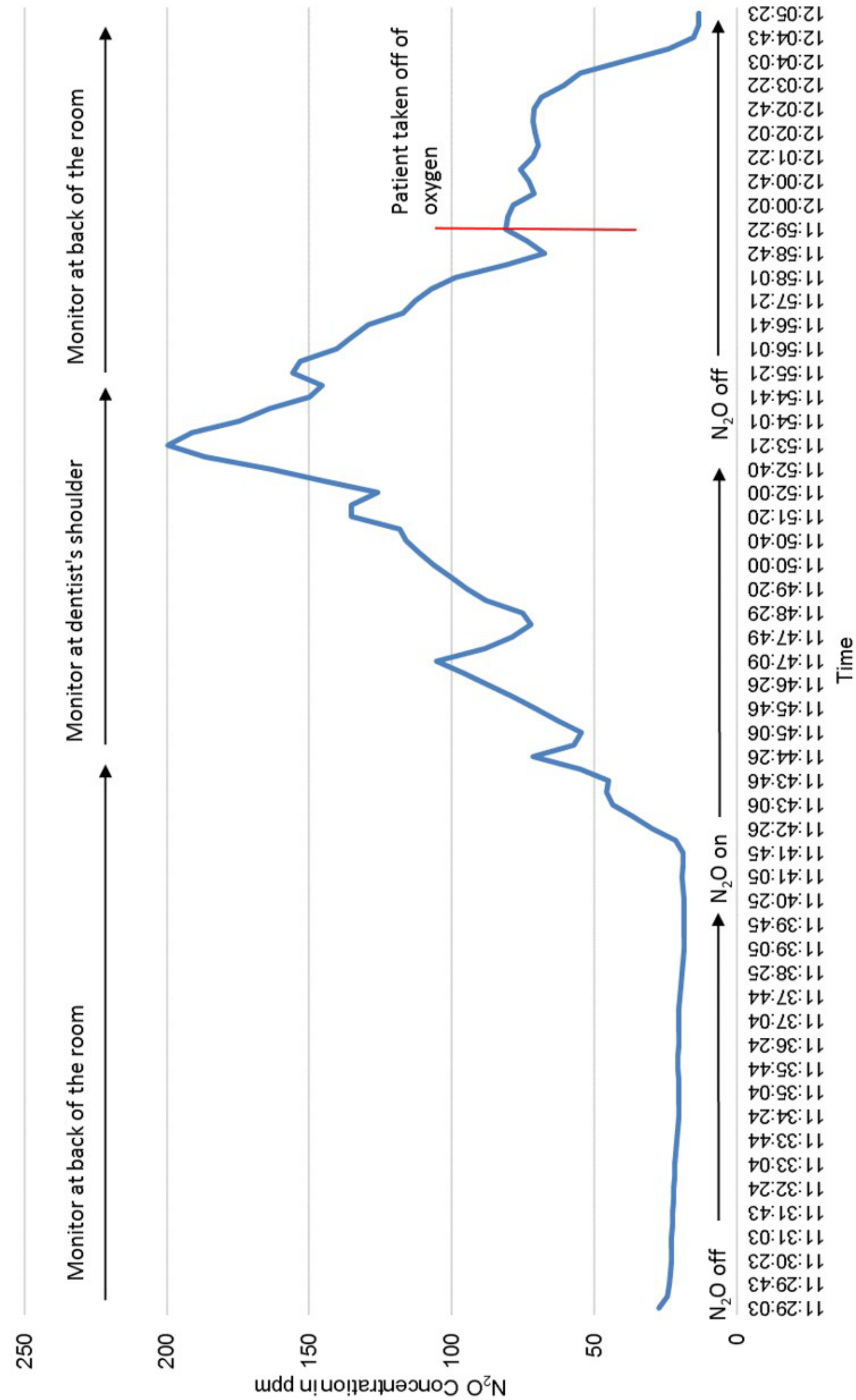


Figure B3. Line graph of $N_2O$ concentrations during patient administration in OP-2.

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