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Occupational Health Stewardship: Thoughts on Current and Future Use of Nitrous Oxide in Pediatric Sedation

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ABSTRACT

Nitrous oxide is a well-tolerated, colorless, odorless gas with medical applications that facilitate procedural sedation and operative care. Like volatile inhalational agents used by anesthesia, nitrous oxide poses occupational health hazards to serially exposed clinicians and, as a greenhouse gas, has environmental consequences. While the anesthesia community has encouraged significant reduction or elimination of nitrous oxide, non-anesthesiologists supporting pediatric procedural sedation outside of the operating room continue to value the use of nitrous oxide, as it is safely applied without requirement for advanced airway devices and does not compound the patient's recovery from subsequently administered sedatives. Responsible use of nitrous oxide entails optimization of those aspects of gas delivery practices that are modifiable, and sedation teams can benefit from collaboration with occupational and environmental health experts. Following a recent longitudinal process improvement project with Industrial Hygiene, we present an editorial discussion on three concepts that influence our perspective on current and future use of nitrous oxide for procedural sedation in the pediatric population. Specifically, we discuss the risk of leak inherent to all gas delivery systems, present options to mitigate nitrous oxide's carbon footprint, and explore the growing demand for pediatric sedation services outside of the traditional operating room.

Introduction

Occupational health is a multidisciplinary field focused on worker well-being and employee safety. The World Health Organization places occupational health under the public health umbrella and encourages development of policies and action plans to codify and improve worker health and safety around the globe.[1] The scope of this discipline is vast and includes industrial hygienists, safety specialists, engineers, environmentalists, and clinicians, among others. Various organizations implement occupational health programs differently, but all aim to steward personnel resources, provide safe working environments, and meet established regulatory standards. To best achieve these aims, management and employee stakeholders collaborate and engage in ongoing cycles of continuous process improvement.

The global healthcare industry generates a significant volume of waste products (over 13 kilograms of waste per hospital bed per day) to provide care for the ill and injured.[2] Solid waste such as hypodermic needles, medical devices, items contaminated with human tissue or body fluids, chemical solvents, expired pharmaceuticals, and radioactive materials can have far-reaching human and environmental impact if disposal is mismanaged. Waste of medical gases that facilitate sedation and operative care also have occupational and environmental impact, but especially with colorless, odorless gases like nitrous oxide (N_2O), these consequences are not as readily noticeable.

From an environmental perspective, N_2O – as well as the volatile anesthetics used exclusively by anesthesia – are greenhouse gases with global warming consequences. For clinicians in this field, occupational exposure can occur episodically over the course of a long career. Occupational exposure limits for sedative gases serve as guardrails to protect the clinical workforce and encourage mindful work practices to reduce dispersion of these gases into the environment. While there is no global consensus on occupational exposure limits for N_2O, both the National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH) have published guidelines for the United States. NIOSH endorses a recommended exposure limit (REL) of 25 parts per million (ppm) during a single N_2O administration event, while ACGIH recommends a time-weighted average (TWA) of 50 ppm in an 8-hour workday.[3]

In our recent article, "Dosimetry as a Lagging Indicator of Occupational Exposure to Nitrous Oxide in Pediatric Sedation," we describe a process improvement project aimed to reduce N_2O occupational exposure from a portable delivery system in a tertiary care medical center.[4] An Industrial Hygiene (IH) survey of a single sedated procedure in our clinic revealed that all sedation team members were exposed to ambient N_2O levels that far exceeded regulatory thresholds. Our primary outcome measure for this project was reduction in dosimetry levels below the NIOSH REL for all team members. Using a FOCUS Plan-Do-Check-Act process improvement model with an interrupted time series design, we standardized facemask application and gas initiation practices as our studied interventions. These modifications correlated with ambient N_2O levels (< 5-8 ppm) well below the NIOSH REL (25 ppm) as registered by dosimetry badges during a short-interval follow-up IH survey. These results were largely sustained over 17 months in the post-intervention phase, and periodic dosimetry monitoring continues to present day. In reflecting on this study and its outcomes, three key concepts surfaced to influence our perspective on current and future use of N_2O in the pediatric population. Regarding the first of these concepts, all gas delivery systems pose risk of leak.

INHERENT RISKS OF LEAK WITH GAS DELIVERY SYSTEMS

Nitrous oxide has a longstanding clinical history and a good patient safety profile with few documented adverse events.[5-6] N_2O affords dose-

dependent sedative and amnestic properties, leads to rapid emergence once discontinued, and lacks noxious odor and taste. In the United States, the Food and Drug Administration (FDA) classifies N_2O as an analgesic agent,[7] which supports its utilization in environments outside of the traditional operating room (OR). Yet, regardless of location of use, there are two main sources of leak to consider with any gas delivery system.

Mask Inductions

Studies in the 1970s-1980s support an association between occupational N_2O exposure and health consequences.[8] As N_2O is exhaled from the alveoli chemically unchanged, much of this research was conducted before widespread adoption of waste gas scavenging systems. Scavenging systems pull exhaled gases away from the patient into a central vacuum or dedicated waste anesthetic gas disposal (WAGD) system. However, even the most efficient scavenging systems can only redirect exhaled gases captured through a well-maintained facemask seal.

N_2O delivery in dental and obstetrics environments are typically demand flow systems, meaning that the patient must inhale and generate a negative pressure deflection registered by the machine to start the forward flow of gas. In contrast, N_2O and volatile anesthetics administered in the hospital are continuous flow systems, whereby initiation of gas flow is not patient triggered. With either system, a proper facemask seal is essential to ensure the patient receives the medication as intended while minimizing N_2O contamination of the procedural space.

During mask induction, inhalational agents are administered in a mixture of fresh gas flow (FGF). FGF matching a patient's minute ventilation can accelerate the onset of sedative effect.[9] However, many patients, especially children, vocalize while masked. A child's initial acceptance of a facemask is far from guaranteed, and screaming, talking, and singing create small, episodic leaks in the seal. Even seemingly simple procedures for children can be resource-intensive, requiring partnership with parents, child life specialists, and a stepwise approach to balance patient comfort, team safety, and procedural success. Given these masking challenges, clinicians may attempt to compensate for an anticipated loss of mask seal by utilizing high FGF that exceeds minute ventilation.[9] With continuous flow systems, this wastes the inhalational agent and can acutely compound occupational exposure. Similarly, adult patients utilizing on-demand systems must cooperate with medical instructions to exhale into the facemask, lest exhaled gases leak into the procedural space.

Pipeline Vs. Cylinder Systems

Medical gases are supplied through central pipeline systems and by portable compressed gas cylinders. Pipeline systems rely on a surplus of gas to continuously pressurize pipes, valves, and manifolds that may be remote from the terminal point of service, typically an OR.[10] Leaks that arise from pipeline systems are likely hidden within engineering infrastructure and often undetected, representing an insidious source of waste. Published reports from the United Kingdom (UK) and Australia report leak of 77-95% of N_2O initially supplied to hospitals for pipeline delivery.[11] While the Australian group did locate a point source of leak ("single old O ring on an N_2O wall outlet"), such a strategy is tedious and inefficient to tackle the scope of this problem.

With an emphasis on the financial and environmental ramifications of this degree of leak from centrally supplied systems, five Anesthesia societies in the UK and Ireland jointly published a consensus statement in 2024 recommending healthcare organizations actively decommission N_2O pipeline systems and transition to portable cylinders.[12] The American Society of Anesthesiologists made similar recommendations in their longstanding consensus statement on Environmental Sustainability in Anesthesia Practice, also last revised in 2024.[13] Although leaks from pipeline N_2O systems were first quantified several years before these consensus statements

were published, decommissioning processes must compete for priority with other capital improvement projects and may lack universal support. Many in the anesthesia community call for minimizing or eliminating N_2O altogether in favor of other inhalational agents,[9,14] but non-anesthesiologists performing natural airway sedations outside of the OR frequently consider N_2O a key component to procedural success (often facilitating intravenous catheter placement for delivery of subsequent sedatives). As one such non-anesthesiologist sedation group, we agree with Southall et al. in that "priority should be given to changing the way the drug is supplied rather than getting bogged down in encouraging individual colleagues to abandon the clinical use of nitrous oxide altogether."[10]

Our pediatric sedation service utilizes a portable, continuous flow, titratable (0-70% N_2O), full-facemask system with gases supplied by oxygen and N_2O e-cylinders. Gas cylinders are turned off when not in use. We concede that even portable, cylinder-based delivery systems contain pressurized gas hose connections that are not designed to be serviced by the end user. As such, IH afforded us access to rigorous evaluations using serial dosimetry and point-source leak assessments of our cylinder and hose connections. As a hospital-based service prone to turnover of personnel and continued use of aging equipment, such occupational health tools can serve as warning signals to focus further investigation, when needed.

NITROUS OXIDE ENVIRONMENTAL IMPACT

Nitrous oxide, as well as all volatile anesthetics, are greenhouse gases that trap heat within the atmosphere. The United States Environmental Protection Agency cites the average atmospheric concentration of N_2O as 0.336 ppm, as of 2022 data.[15] The global warming potential of individual anesthetics on a 100-year time scale (GWP_{100}) is a measure of the radiative properties of each gas compared to carbon dioxide (CO_2). N_2O has a GWP_{100} of 265 to 300 times that of CO_2 and can persist in the atmosphere for over 100 years.[9,11,14] By comparison, the commonly used anesthetic sevoflurane has a more favorable, but still significant, GWP_{100} of 144 times that of CO_2 and only 1 atmospheric lifetime.[14]

Occupational health literature defines engineering controls as physical constructs aimed to remove contaminants or reduce employee exposures.[16] With medical gases, engineering controls include such things as dilutional ventilation, forced air exchanges, and scavenging systems. As opposed to decades earlier, clinicians administering inhalational agents now endorse near universal adoption of waste gas scavenging.[17-18] Specific to N_2O, the captured exhalation is redirected into a vacuum or WAGD line that vents the gas to the outside atmosphere without chemical alteration. We must acknowledge that while effective scavenging minimizes occupational exposure to clinicians in the procedural area, it shifts the receiving location of exhaled N_2O to the global atmosphere.

One option to reduce this carbon footprint is to 'crack' scavenged N_2O into its nitrogen (N_2) and oxygen (O_2) non-greenhouse component gases through catalytic destruction. As demonstrated through bench research simulating ideal conditions, this technology could theoretically eliminate all N_2O occupational exposure and environmental consequences.[19] However, perfection is rarely achieved in clinical settings. Pinder et al. subsequently described the use of N_2O cracking technology placed in line with a demand flow N_2O delivery system for laboring mothers.[20] The authors gave significant attention to optimizing scavenging potential through selection of the most comfortable and non-obtrusive patient interface available, as exhaled gases not captured in the facemask bypassed the cracking technology. Although a portable device, the cracking unit occupied significant floor space, especially notable when placed in a procedural suite crowded with

other medically necessary personnel and equipment. The authors suggest that cracking technology could be integrated into hospital systems through augmentation of central vacuum or WAGD systems, but similar to the N_2O pipeline decommissioning discussion previously, cost or competing priorities may preclude widespread adoption, especially without a mandate for it from an environmental regulatory body.

Although cracking has not yet transitioned into mainstream clinical practice, we can continue to innovate and improve the aspects of gas delivery practices that are modifiable. For example, by standardizing our masking technique and extending the duration of exhaled scavenging, we achieved a notable reduction in ambient N_2O levels by dosimetry. Using cylinder systems that are turned off when not in use avoids most indiscernible leaks associated with pipeline supply systems. A deep appreciation of the potential occupational and environmental consequences of N_2O affords clinicians a comprehensive perspective for the rationale behind such improvement initiatives.

DEMAND FOR PEDIATRIC SEDATION OUTSIDE OF THE OPERATING ROOM

Efforts to reduce healthcare's carbon footprint must also consider unique clinical settings where inhalational sedatives remain essential.[21-22] Pediatric sedation occupies this intersection between environmental stewardship and patient need. The same agents with concerns for occupational and environmental exposure are, paradoxically, those that make many procedures tolerable and, in many cases, possible for children. As such, pediatric sedation is a useful model for examining how health systems can pursue safety and sustainability without compromising access or quality of care.

Aside from improving the odds of procedural success, pediatric sedation is critical to safeguarding children's psychological health.[23] This is particularly evident in the pediatric oncology population, where repeated or distressing medical experiences can condition fear responses, amplify physiological stress, and contribute to long-term healthcare avoidance.[24-25] When paired with behavioral and environmental strategies, sedation serves both therapeutic and preventive functions by supporting emotional well-being and improving cooperation with the healthcare team. The presence of child life specialists, sensory-adapted environments, and active parental participation reflects a more holistic understanding of procedural comfort that extends beyond pharmacology. For children with chronic illness, developmental delay, or neurodivergent conditions, such multimodal approaches are often vital to achieving procedural safety and success.[26-27]

This evolving perspective has paralleled a steady expansion of pediatric sedation services over the past two decades, reflecting both clinical necessity and organizational adaptation.[28] An increasing number of diagnostic and therapeutic procedures are now performed without general anesthesia, and expectations for patient comfort and efficiency continue to rise.[29-30] Outside the OR sedation services conducted in radiology suites, oncology infusion centers, emergency departments, and dedicated sedation units have experienced exponential growth. Although anesthesiologists can also perform these natural-airway sedations, their intraoperative expertise is leveraged by hospital systems to support an expansion of surgical services. As such, sedations performed by qualified non-anesthesiologist clinicians, including pediatric hospitalists, emergency physicians, intensivists, and radiologists, directly offload anesthesia services while preserving, if not improving, procedural access. This shift has diversified the sedation workforce and redistributed procedural care toward ambulatory and subspecialty environments.[30-33] Evidence supports the safety and effectiveness of such models when guided by institution-specific credentialing frameworks and professional society

consensus recommendations.[23,28] Even so, application of these models remains heterogenous across institutions in terms of sedative medications used, staffing ratios, recovery standards, and emergency response capabilities.[34] This variation underscores that sedation safety depends on alignment of patient factors, procedural requirements, clinical environment, and institutional infrastructure.

Non-OR sedation differs from anesthesia practice in both capability and intent. Sedations by non-anesthesiologists are typically planned as natural-airway procedures, relying on effective spontaneous ventilation to avoid the need for invasive airway management. Inhaled anesthetics such as sevoflurane require specialized delivery equipment and credentials for use that typically limit administration to anesthesiologists. As a result, non-OR sedation programs rely on intravenous and inhaled agents that can be administered safely and without advanced airway devices. N_2O remains a valuable option in this setting, particularly for short duration, moderately painful procedures, or as a bridge to intravenous sedation. Its minimal interaction with subsequently administered sedatives and lack of prolonged recovery further enhance efficiency and predictability in outpatient and ambulatory care.[29,35-36]

N_2O utilization in diverse clinical locations invites renewed attention to occupational and environmental considerations. Non-OR areas vary in ventilation, scavenging capacity, and engineering controls. Portable, cylinder-based delivery systems eliminate concerns from pipeline systems as discussed earlier, but these systems contain pressurized connections that can become sources of small, cumulative gas leaks. Suboptimal face mask seal, patient vocalization, and high fresh-gas flows can elevate ambient N_2O concentrations. Although various regulatory agencies have recommended exposure limits for N_2O, maintaining compliance can be difficult in procedural spaces not designed for inhaled agents and among teams less familiar with exposure monitoring and mitigation strategies. Thus, the same expansion of services that improve procedural access for children can also increase occupational exposure risk and environmental impact. This makes partnership with Industrial Hygiene and Occupational Health colleagues even more important. Institutions must apply the same diligence to these areas that have long been established within the OR, including regular maintenance, leak testing, scavenging verification, and continuing education.

The growing demand for pediatric sedation outside the OR represents more than an operational shift; it signals an inflection point. Health systems risk decentralizing procedural locations faster than they can develop the safety infrastructure required to support them.[33] Sustained progress in delivering safe, timely, patient-centered sedation care will depend on the application of rigorous occupational and environmental safeguards comparable to those in anesthetizing locations. Standardized training, effective scavenging, investment in emerging technologies (like cracking), and ongoing workplace monitoring are not adjunctive measures but essential features of a mature sedation program. The discipline of occupational health provides the framework through which these aims converge, ensuring that as sedation services expand, they do so safely, sustainably, and with equal regard for patients, clinicians, and the environment.

CONCLUSION

Nitrous oxide typifies the broad challenge facing modern healthcare: maximizing clinical benefit while minimizing harm. Elimination of medications with less than ideal occupational or environmental characteristics restricts access and reduces comfort for those patient populations who may lack effective alternatives. The better path is to modernize where able and strengthen collaboration among clinicians, Industrial

Hygienists, and Occupational Health professionals to ensure responsible and sustainable use of current therapeutics while awaiting the next new pharmaceutical to change the sedation landscape. Demand for pediatric sedation continues to grow, and it cannot be fully met by anesthesiologists alone. N_2O is a clinically attractive option for pediatric sedations performed outside of the traditional OR by non-anesthesia clinicians. Approaching pediatric sedation with a "now and not yet" mindset is not cognitive dissonance. We can deliver quality care now and continue to improve efforts to protect the patient, the workforce, and the world in which that care is provided.

DISCLAIMER:

The views expressed in this article are those of the authors and do not necessarily reflect the official policy of the Department of War or the U.S. Government.

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