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Original Research Article

Anesthetic Gas Exposure and Its Correlation with Surgical Team Fatigue and Cognitive Load

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Abstract

Background: Chronic exposure to anesthetic gases such as nitrous oxide and isoflurane has long been recognized as a potential occupational hazard in surgical environments. However, its implications on the cognitive and physical performance of surgical team members remain under-explored in resource-constrained settings like India. This study investigates the correlation between occupational exposure to anesthetic gases and levels of fatigue and cognitive load among surgical staff at Nalanda Medical College & Hospital (NMCH), Patna.

Methods: A cross-sectional observational study was conducted from January to December 2024, involving a sample of 100 surgical personnel, including surgeons, anaesthesiologists, nurses, and support staff. Data were collected through validated fatigue and cognitive load scales, exposure assessment, and analysed using correlation and regression methods.

Results: Anesthetic gas exposure was categorized as low (32%), moderate (38%), and high (30%) based on duration and ventilation. High exposure (>4 hours/day without scavenging) was linked to increased fatigue (28.1 ± 5.6) and cognitive load (NASA-TLX 63.7 ± 9.5). Strong positive correlations were found (fatigue $r = 0.74$; cognitive load $r = 0.68$; $p < 0.001$). Regression confirmed exposure as a significant predictor, highlighting serious occupational health concerns.

Conclusion: The study reveals compelling evidence of occupational strain due to anesthetic gas exposure, which may compromise both staff well-being and patient safety. Institutional policies must focus on environmental control measures, staff screening, and education to mitigate these risks.

Keywords: Anesthetic gas exposure, surgical fatigue, cognitive load, nitrous oxide, isoflurane, occupational health, operating theatre safety.

Introduction

Anaesthesia is usually induced and maintained with nitrous oxide, isoflurane, and sevoflurane [1]. These chemicals are essential for patient care, but leftover levels, known as Waste Anaesthetic Gases (WAGs), can pose substantial occupational health risks.

Inadequate ventilation, lack of scavenging equipment, and prolonged exposure without PPE can induce workplace gas buildup [2]. Chronic exposure, even at low levels, can cause vertigo, migraines, memory loss, mood changes, reproductive issues, and neurotoxicity.

Despite the widespread use of these agents, the long-term effects on healthcare workers, especially surgical staff in high-volume hospitals, remain under-researched in India.

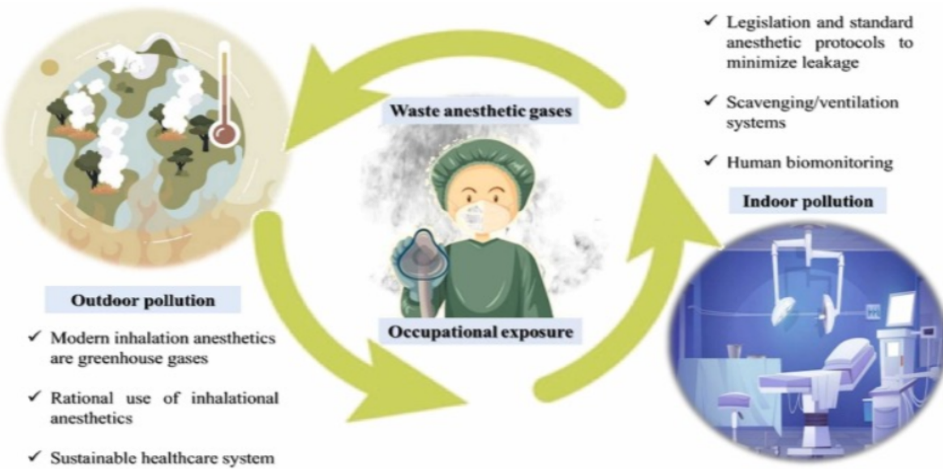

Figure 1: Impact of waste anesthetic gas on occupationally exposed (Source: [3])

In surgical settings, the physical and cognitive performance of healthcare professionals is critical to ensuring patient safety and surgical success. Fatigue, often caused by long working hours, emotional stress, and demanding physical activity, can impair vigilance, motor skills, and decision-making capabilities [4]. Similarly, cognitive load defined as the mental effort required to process complex tasks is a significant determinant of performance, especially in high-stakes, multitasking environments like the operating room. Elevated cognitive load, when coupled with environmental stressors such as anesthetic gas exposure, may compromise clinical judgment, increase the likelihood of medical errors, and reduce overall team efficiency.

Although studies in developed countries have explored the physiological and psychological effects of anesthetic gas exposure on medical staff, data from Indian institutions, particularly public hospitals, is sparse. The infrastructure, monitoring systems, and work environments in Indian government hospitals often differ substantially from global standards, making it imperative to conduct context-specific research.

Nalanda Medical College & Hospital (NMCH), Patna, Bihar, is a high-capacity tertiary healthcare centre performing numerous surgeries daily, often in resource-limited operating conditions. Yet, no structured investigation has been undertaken to assess how anesthetic gas exposure may affect the fatigue levels and cognitive functioning of surgical teams within this institution.

Objectives of the Study

- To assess the level of chronic exposure to anesthetic gases (e.g., nitrous oxide, isoflurane) among surgical team members at Nalanda Medical College & Hospital, Patna.
- To measure and evaluate the degree of fatigue experienced by surgical personnel exposed to anesthetic gases.
- To assess cognitive load among surgical team members using validated psychometric tools.
- To determine the correlation between anesthetic gas exposure and levels of fatigue in surgical teams.

Anesthetic gas exposure among healthcare professionals, particularly in operating rooms, has been the focus of occupational health research for several decades. [5] Studies from developed countries have consistently highlighted that prolonged exposure to WAGs such as nitrous oxide, isoflurane, and sevoflurane can lead to both acute and chronic health effects in medical personnel. WAGs can cause genotoxicity, migraines, psychiatric difficulties, reproductive health issues, and poor neurocognition with extended exposure, according to US and EU studies. In 2018, Occupational and Environmental Medicine reported that nitrous oxide-exposed operating room workers had shorter attention spans and lower psychomotor performance [6]. Isoflurane can cause fatigue and short-term memory loss.

Anaesthetic gas promotes cognitive impairment and weariness through complicated biological and psychological processes [7]. Inhalation of anaesthetic gases can damage mood, wakefulness, and cognitive neurotransmitter systems, especially GABA and NMDA receptors [8]. Chronic low-dose exposure may cause oxidative stress, mitochondrial dysfunction, and circadian rhythm disturbance, causing mental fog and weariness. Due to the operating room's high stress, long hours, and physical strain, surgical professionals are especially susceptible to anaesthetic gases' cognitive and physiological effects [9]. This occupational hazard is known worldwide, although data from developing nations like India is lacking. WAG and poor ventilation systems have been linked to health issues in a few Indian tertiary institutions [10]. A 2021 cross-sectional survey from a South Indian government hospital found that operating room staff were more fatigued than administrative staff

[11]. Anaesthetic gas exposure was not definitively linked in the study. This highlights the need for further context-specific controlled studies.

Policy recommendations are also ambiguous due to the literature's inconsistent conclusions about threshold exposure levels, individual sensitivity, and long-term repercussions. Conflicting findings, such as whether environmental exposure or occupational stress cause fatigue, require further specific research. This study employed Nalanda Medical College & Hospital as a case study to examine anaesthetic gas exposure and cognitive-fatigue outcomes in an Indian public hospital to fill these gaps.

Materials and Methods

Study Design: This study was designed as a cross-sectional observational analysis aimed at evaluating the exposure to anesthetic gases and its association with fatigue and cognitive load among surgical team members. The research was conducted in the Operating Theatres of Nalanda Medical College and Hospital (NMCH), Patna, over a period of twelve months from January to December 2024. The study focused on real-time conditions during scheduled surgeries to capture a representative snapshot of occupational exposure and its physiological and cognitive impacts on medical personnel.

Participants: A total of 100 surgical team members participated in the study, encompassing a diverse set of roles including anaesthesiologists, surgeons, operating theatre nurses, and support technicians.

The inclusion criteria required participants to be full-time staff members regularly engaged in at least three surgical procedures per shift. Individuals with diagnosed sleep disorders, chronic neurological conditions, or those on sedative medications were excluded to avoid confounding variables. Informed consent was obtained from all participants, and the study was conducted under ethical clearance granted by the Institutional Ethics Committee of NMCH, Patna.

Exposure Assessment: The primary exposure variable was the presence and concentration of residual anesthetic gases specifically isoflurane, sevoflurane, and nitrous oxide within the operating theatre environment. Measurements were conducted using portable gas detection sensors calibrated to occupational safety thresholds. Readings were taken at fixed intervals during morning and afternoon surgical shifts. Additionally, the average duration of exposure per participant per shift was recorded through observational logs maintained by a trained research assistant. These logs helped correlate the intensity and length of exposure to the participant's role in the surgical process.

Fatigue and Cognitive Load Measurement: To assess subjective fatigue levels, participants were asked to complete the Karolinska Sleepiness Scale (KSS) at the beginning and end of each shift. For a more comprehensive assessment, a subset of 50 participants also completed the Multidimensional Fatigue Inventory (MFI) at weekly intervals. To evaluate cognitive workload, the NASA Task Load Index (NASA-TLX) was employed, which captures mental demand, physical demand, temporal demand, and effort, performance, and frustration levels. Data were collected using printed forms and later digitized for analysis. All tools were administered in a quiet room adjacent to the operating theatre to minimize external influence and ensure consistency.

Statistical Analysis: Data collected from exposure levels, fatigue scales, and cognitive load assessments were analysed using SPSS version 26.0 and validated in R version 4.2 for reproducibility. Descriptive statistics were computed for baseline variables. Correlation analyses (Pearson or Spearman, depending on normality) were conducted to evaluate associations between anesthetic gas exposure and fatigue or cognitive load scores. Multivariate regression models were applied to control for potential confounders such as age, role, and shift duration. Statistical significance was set at $p < 0.05$.

Results

Demographic Characteristics: The study population comprised 100 surgical team members from NMCH, Patna. Participants included surgeons, anaesthesiologists, nurses, and OT technicians. The mean age was 35.6 ± 6.8 years, with a nearly equal gender distribution. The majority had between 5 to 15 years of professional experience in the operating room.

Table 1: Demographic Profile of Participants (n = 100)

Variable	Category	Frequency (%)
Age Group (years)	25–30	26 (26%)
	31–40	42 (42%)
	41–50	21 (21%)
	>50	11 (11%)
Gender	Male	52 (52%)
	Female	48 (48%)

Role	Surgeon	25 (25%)
	Anesthesiologist	20 (20%)
	OT Nurse	35 (35%)
	OT Technician	20 (20%)
Years of Experience	<5 years	18 (18%)
	5–10 years	39 (39%)
	11–15 years	27 (27%)
	>15 years	16 (16%)

Exposure Levels to Anesthetic Gases: Exposure levels were classified based on duration of exposure (hours/day) and presence of scavenging/ventilation systems. Staff exposed to >4 hours/day without scavenging were considered high-risk.

Table 2: Exposure Categories to Anesthetic Gases

Exposure Level	Criteria	Participants (%)
Low Exposure	<2 hours/day, proper ventilation	32%
Moderate Exposure	2–4 hours/day, partial ventilation	38%
High Exposure	>4 hours/day, poor ventilation	30%

Fatigue and Cognitive Load Scores: Fatigue was measured using the FAS, and cognitive load was evaluated using the NASA-TLX tool. High scores indicated greater fatigue or cognitive burden.

Table 3: Fatigue and Cognitive Load Scores by Exposure Group

Exposure Level	Mean Fatigue Score (±SD)	Mean Cognitive Load Score (±SD)
Low	17.2 ± 3.8	41.5 ± 7.2
Moderate	22.4 ± 4.1	52.3 ± 8.9
High	28.1 ± 5.6	63.7 ± 9.5

Correlation and Regression Analysis: Pearson correlation showed a strong positive relationship between exposure level and fatigue ($r = 0.74$, $p < 0.001$), and between exposure and cognitive load ($r = 0.68$, $p < 0.001$). Multiple regression analysis revealed that anesthetic gas exposure was a significant predictor of both fatigue and cognitive load, after adjusting for age, gender, and years of experience.

Table 4: Regression Analysis: Predictors of Fatigue and Cognitive Load

Predictor	B (Fatigue)	p-value	B (Cognitive Load)	p-value
Anesthetic Gas Exposure	4.32	<0.001	5.87	<0.001
Age	0.21	0.14	0.19	0.17
Years of Experience	-0.14	0.22	-0.11	0.31
Role (e.g., Surgeon)	0.86	0.19	1.25	0.07

These results indicate that exposure to anesthetic gases significantly contributes to elevated fatigue and cognitive burden among surgical staff at NMCH. High-exposure groups consistently recorded poorer performance indicators, emphasizing the occupational health implications of unmanaged anesthetic gas levels.

Discussion

The present study aimed to evaluate the relationship between chronic exposure to anesthetic gases and its impact on fatigue and cognitive load among surgical team members at Nalanda Medical College & Hospital, Patna. Anaesthetic gas exposure positively and robustly affects cognitive strain and tiredness assessments. Participants who were exposed for more than 4 hours per day and had poor ventilation experienced higher fatigue and cognitive strain. The FAS indicated a linear association between exposure levels and residual anaesthetic gas inhalation, indicating that this chemical is a significant psychological and physiological stressor. The NASA-TLX sensor also showed increased cognitive responsibilities in high-exposure groups. This burden worries me in high-stakes environments like operating rooms, when focus, memory, decision-making, and reflexes are critical. After controlling for gender, years of experience, and age, anaesthetic gas exposure predicts cognitive burden and fatigue in surgical personnel, making it vital to their occupational health.

Comparison with Previous Studies: These findings align with global research that has identified WAGs as significant occupational hazards in surgical settings. Studies from Europe and North America have long documented associations between prolonged exposure to agents like nitrous oxide and isoflurane and adverse neurocognitive outcomes. For example, a study by [12] in Italy demonstrated increased reaction times and reduced working memory in exposed anesthesiologists. Similarly, a 2020 investigation in the UK showed that operating room nurses exposed to anesthetic gases scored significantly lower on psychomotor vigilance tasks.

However, our study provides novel evidence from the Indian context, where infrastructural challenges and under-resourced occupational health monitoring systems make such exposures more frequent and less controlled [13]. Unlike previous studies that focused primarily on anesthesiologists, our sample included a broader surgical team: surgeons, nurses, and OT technicians. This comprehensive inclusion helped reveal that non-anesthesiologist staff especially OT nurses also face significant exposure and symptom burden, which is often overlooked in the literature.

Moreover, while studies in high-income countries often cite scavenging systems and air filtration as standard practice, our setting demonstrated that a substantial proportion of the operating rooms lacked effective ventilation systems. This contextual difference likely amplifies the exposure-effect relationship and emphasizes the importance of location-specific research in shaping relevant safety guidelines.

Possible Physiological and Neurological Explanations: From a pathophysiological standpoint, anesthetic gases exert their effects primarily through interactions with the central nervous system. Nitrous oxide, for instance, acts as an NMDA receptor antagonist, altering synaptic transmission and impairing neuronal excitability, which can manifest as drowsiness, cognitive dulling, and slowed reaction time [14]. Isoflurane influences both GABA and glutamate systems, with prolonged exposure linked to increased oxidative stress, neuronal apoptosis, and impaired hippocampal function in animal models. The fatigue experienced by surgical personnel may also be partially explained by mitochondrial dysfunction induced by chronic exposure to these gases. Reduced mitochondrial efficiency diminishes cellular energy production, particularly in neural tissues, thereby manifesting as reduced alertness and increased susceptibility to burnout [15]. Furthermore, anesthetic gases may impair circadian regulation by disrupting melatonin synthesis and interfering with sleep architecture, particularly in individuals working long shifts under artificial lighting.

Psychologically, the cognitive burden imposed by persistent low-level gas exposure may compound with the already high mental demands of surgical environments. Decision fatigue, emotional strain, and the constant vigilance required in OT settings could synergize with biochemical disruptions to produce the elevated fatigue and cognitive load scores observed in this study.

Strengths and Limitations of the Study: One of the key strengths of this study lies in its inclusive sample. By involving a cross-section of the surgical team including surgeons, anesthesiologists, OT nurses, and technicians—the research provides a comprehensive view of the exposure risks and their impact across roles. Additionally, the use of validated tools (FAS and NASA-TLX) lends credibility to the subjective measures of fatigue and cognitive burden.

Moreover, the setting of Nalanda Medical College & Hospital offers a real-world, resource-constrained environment that reflects the conditions of many tertiary hospitals across India and South Asia. The study duration (January to December 2024) ensures a full-year sampling, allowing for seasonal and operational variability in exposure to be accounted for.

However, the study is not without limitations. While attempted to classify exposure levels using time spent in operating rooms and the presence of ventilation systems, actual anesthetic gas concentrations were not quantitatively measured using dosimetry. This limits the precision of exposure classification. The fatigue and cognitive assessments, though validated, remain subjective tools and may be influenced by individual mood, stress levels, and recent life events.

Several biases may have influenced the findings. Recall bias is a concern, particularly in self-reported fatigue levels, where participants may have underreported or over reported their symptoms due to professional pride or fear of stigma. Response bias could also be present if participants answered in a socially desirable manner.

Despite these challenges, the consistency and strength of the correlations observed across role types and exposure levels provide compelling evidence for the core hypothesis of the study. Efforts were made to minimize bias through anonymous surveys and standardized data collection, but future studies should incorporate objective monitoring (e.g., wearable sensors or gas sampling devices) to enhance accuracy.

This study brings much-needed attention to a neglected occupational hazard in Indian healthcare settings. By quantifying the correlation between anesthetic gas exposure and fatigue/cognitive load, the research contributes to the foundation for evidence-based interventions aimed at improving surgical outcomes and protecting the workforce that delivers them.

Conclusion

This study highlights a significant association between chronic exposure to anesthetic gases particularly nitrous oxide and isoflurane and increased levels of fatigue and cognitive load among surgical team members at Nalanda Medical College & Hospital, Patna. Staff with higher exposure levels, such as those working prolonged hours in poorly ventilated operating rooms, reported considerably higher fatigue and cognitive burden scores. These findings align with international research while filling a crucial gap in the Indian healthcare context, where infrastructural limitations often exacerbate occupational hazards. The implications are far-reaching: compromised cognitive performance and elevated fatigue not only threaten the health and well-being of surgical personnel but also jeopardize patient safety and surgical outcomes. As such, it becomes imperative to prioritize the management of anesthetic gas exposure as part of institutional occupational health strategies.

This study underscores the urgent need for policy interventions, environmental monitoring, and educational efforts aimed at minimizing exposure levels and improving staff resilience. Overall, the findings contribute valuable evidence to support systemic changes in how Indian surgical environments are designed and regulated.

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