Original Article

# Multilayer intraoperative monitoring: clinical use of capnography during neuraxial block in Port Harcourt, Nigeria

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## Abstract

**Background:** The concept of multilayer defence, often applied in advanced air defence systems, is also relevant in perioperative patient safety through the use of multiple, complementary monitoring modalities. Capnography, which provides continuous real-time assessment of end-tidal carbon dioxide ($EtCO_2$), is traditionally employed during general anaesthesia but has emerging value as an additional layer of intraoperative monitoring during neuraxial anaesthesia.

**Aim:** To evaluate the impact of incorporating capnography as an adjunct to standard monitoring on respiratory event detection and patient satisfaction during neuraxial anaesthesia.

**Methods**: A randomised controlled trial was conducted across five hospitals in Port Harcourt, Nigeria, all equipped with capnography facilities. A total of 250 adult patients undergoing elective surgery under neuraxial anaesthesia were randomly allocated to two groups: Group A (standard monitoring) and Group B (standard monitoring plus capnography). Primary outcomes included the ability to detect apnoea, sedation-related respiratory changes, and sudden desaturation. Secondary outcomes were operative duration and patient satisfaction. Data were analysed using IBM SPSS version 26.

**Results:** Capnography enabled earlier detection of desaturation events—within 20 seconds—compared to pulse oximetry, and identified apnoea and sedation-related respiratory pattern changes in 98% of cases. No significant difference in operative duration was observed between the two groups. Patient satisfaction was significantly higher in the capnography group (mean score: $4.5 \pm 0.4$) compared to the standard monitoring group ($3.9 \pm 0.5$; $p < 0.001$).

**Conclusion:** The addition of capnography to standard monitoring during neuraxial anaesthesia significantly enhances perioperative safety through earlier recognition of respiratory compromise and improved patient satisfaction.

**Keywords:** Multilayer monitoring, capnography, neuraxial block, perioperative safety, randomised controlled trial, Port Harcourt

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## INTRODUCTION

Patient safety during neuraxial anaesthesia necessitates a proactive and comprehensive approach to intraoperative monitoring. Relying solely on a single monitoring modality is often inadequate for detecting subtle or evolving physiological disturbances, particularly in spontaneously breathing patients. Adopting a multilayered monitoring strategy—where supplementary tools such as capnography are integrated with standard monitoring techniques—enhances clinical vigilance, facilitates timely intervention, and reduces the likelihood of preventable complications.[1]

The authors of this paper had managed patients in the intensive care unit (ICU) in Port Harcourt, Nigeria, who developed hypoxic ischaemic encephalopathy with very poor outcomes following respiratory failure during neuraxial block. These unfortunate experiences underscore the critical need for extra vigilance in spontaneously breathing patients and highlights the importance of adopting a multilayered monitoring approach. Capnography provides continuous, real-time information on ventilation status, serving as a vital complement to traditional monitors such as pulse oximetry, temperature, urine output, electrocardiogram (ECG), and non-invasive blood pressure.[2]

Neuraxial anaesthesia, comprising both spinal and epidural techniques, remains a cornerstone of anaesthetic practice for surgeries involving the lower abdomen, pelvis, and lower limbs. It is widely performed in anaesthetic practice and even more so in low-resource settings, including Nigeria. Its well-recognised benefits include reducing the cost associated with general anaesthesia—an important consideration in Nigeria—lower systemic drug exposure, decreased risk of postoperative nausea and vomiting, superior analgesia, and preservation of spontaneous breathing.[3] However, neuraxial anaesthesia is not without risk. Respiratory and cardiovascular complications such as acute respiratory failure, hypoxia, bradycardia, and hypotension can still occur, especially when monitoring is limited to basic tools like pulse oximetry and non-invasive blood pressure.[4,5]

Capnography, which provides continuous non-invasive monitoring of end-tidal carbon dioxide ($EtCO_2$), serves as an essential early warning system. Though traditionally used during general anaesthesia and procedural sedation,[6] capnography has proven highly effective in detecting early changes in respiratory parameters. Real-time $EtCO_2$ readings enable clinicians to identify hypoventilation, apnoea, or sedation before the onset of critical deterioration.[7] Leading anaesthesia societies—including the World Federation of Societies of Anaesthesiologists (WFSA), the American Society of Anesthesiologists (ASA), and the World Health Organisation (WHO)—strongly advocate the use of capnography in vulnerable patient populations to enhance perioperative safety.[8,9]

There is growing evidence supporting the extension of capnography use to regional anaesthesia. A prospective study had demonstrated that capnographic monitoring enabled earlier detection of respiratory compromise in sedated patients undergoing spinal anaesthesia, outperforming pulse oximetry in terms of timing and accuracy.[10] Similarly, Weiniger et al. found that $EtCO_2$ monitoring more reliably detected hypoventilation in parturients who received intrathecal opioids during caesarean delivery.[11] These findings reveal that the risk of respiratory compromise persists even in procedures that do not involve airway instrumentation or general anaesthesia. Capnography thus provides an additional layer of safety against unexpected events[12] and is an essential tool for early detection of physiological deterioration, helping avoid unnecessary conversion to general anaesthesia.[13] Its integration into standard practice improves situational awareness, facilitates timely clinical decisions, and significantly reduces the likelihood of adverse outcomes.[14]

The adoption of multilayered monitoring during neuraxial block is, however, often limited by access and availability of equipment. Reports indicate that many anaesthesia providers in low- and middle-income countries (LMICs) lack access to monitors equipped with capnography. Even where such monitors are available, there is a prevailing notion that including capnography for spontaneously breathing, non-sedated patients undergoing neuraxial block is excessive. This study, therefore, aimed to evaluate the impact of incorporating capnography as an adjunct to standard monitoring on respiratory event detection and patient satisfaction during neuraxial anaesthesia in a low-resource setting.

## METHODS

This study was a prospective, randomised controlled trial conducted between January 2022 and February 2025, involving five standard hospitals in Port Harcourt, Nigeria. Each participating hospital had operating theatres equipped with multiparameter monitors (GE and Mindray) that included capnography. The study population consisted of patients aged over 10 years, classified as ASA physical status I, II, or III, who were scheduled for elective surgery under neuraxial anaesthesia without sedation. A total of 250 adult patients who met the inclusion criteria were enrolled in the study after providing written informed consent. Patients were excluded if they had any contraindications to neuraxial anaesthesia, were scheduled to undergo procedures involving sedation or general anaesthesia, or if capnography could not be applied. Additionally, individuals with a history of respiratory disease, obstructive sleep apnoea. Ethical approval for the study was obtained from the Research and Ethics Committees of all participating institutions, and all procedures adhered to the ethical principles outlined in the Declaration of Helsinki.

Participants were randomly assigned to two groups using a computer-generated randomisation sequence. Allocation concealment was maintained using sequentially numbered, sealed opaque envelopes, which were opened immediately before the administration of anaesthesia. Group A, the control group, received standard intraoperative monitoring including non-invasive blood pressure, pulse oximetry, temperature and electrocardiography. Group B, the intervention group, received the same standard monitoring with the addition of continuous side-stream capnography to monitor end-tidal carbon dioxide ($EtCO_2$). All anaesthetic procedures were performed either by the authors or by senior registrars under supervision. The decision to use spinal or combined spinal-epidural anaesthesia, as well as the selection of adjuvant medications, was guided by clinical indications and institutional protocols.

The primary outcome measure was the ability to detect apnoea, respiratory depression, and sudden oxygen desaturation. Apnoea was defined as the cessation of respiratory effort lasting more than 20 seconds. Respiratory depression related to sedation was identified by changes in the $EtCO_2$ waveform morphology or a reduction in respiratory rate to fewer than eight breaths per minute. Sudden desaturation was defined as a rapid decline in peripheral oxygen saturation ($SpO_2$) exceeding five percent from baseline values.

Secondary outcomes included the total duration of the operative procedure, measured from the time of skin incision to wound closure, and the level of patient satisfaction, which was assessed postoperatively using a validated five-point Likert scale ranging from 1 (very dissatisfied) to 5 (very satisfied). An additional secondary outcome was the quality of intraoperative monitoring, assessed using a composite Monitoring Quality Index (MQI) developed specifically for this study. The MQI was constructed to capture five key aspects of monitoring performance: the timeliness of respiratory event detection, the accuracy of detection, the clinician's perceived confidence in the monitoring system, the reliability of the monitor (absence of signal dropout), and whether timely clinical interventions were prompted by the monitoring data. Each component was assigned a weighted score, with the total MQI ranging from 0 to 10, where higher scores reflected superior monitoring quality.

All data were entered and analysed using IBM SPSS Statistics version 26 (International Business Machines Corporation, Armonk, New York, United States of America). Continuous variables were summarised using means and standard deviations, while categorical variables were presented as frequencies and percentages. Between-group comparisons were conducted using independent samples t-tests for continuous data and chi-square tests for categorical variables. A p-value of less than 0.05 was considered statistically significant.

**RESULTS**

The mean age was 39.6 ± 12.4 years in Group A and 38.9 ± 11.7 years in Group B (p = 0.614), with no statistically significant difference. The study population comprised 205 females and 45 males, reflecting the predominance of obstetric and gynaecological procedures. ASA physical status was evenly distributed across both groups (I/II/III: 35/58/32 vs 37/55/33; p = 0.921). The surgical procedures performed included 120 caesarean sections (mean duration: 60 minutes), 80 open abdominal myomectomies (150 minutes), and 50 inguinal hernia repairs (45 minutes), with no significant difference in operative time between groups (p = 0.213) as shown in Table 1.

Capnography significantly enhanced intraoperative monitoring by enabling earlier detection of apnoea, sedation-related respiratory depression, and desaturation. Key outcomes showed a marked reduction in the incidence of hypoxia (3% vs 12%, p = 0.003), desaturation (>5% drop in $SpO_2$: 1% vs 6%, p = 0.016), and bradycardia (<50 bpm: 2% vs 8%, p = 0.012) in the capnography group as shown in Table 2.

Although hypotension occurred slightly less in Group B (14%) compared to Group A (20%), this difference was not statistically significant (p = 0.213). Mean patient satisfaction scores were significantly higher in the capnography group (4.5 ± 0.4 vs 3.9 ± 0.5, p < 0.001). Moreover, the Monitoring Quality Index (MQI), a composite score assessing the performance of intraoperative monitoring, was significantly superior in Group B (8.6 ± 0.9) compared to Group A (5.2 ± 1.1), with a p-value < 0.001 as shown in Table 3.

**Table 1: Baseline demographic and clinical characteristics**

| Measure | Group A (Standard Monitoring) | Group B (Capnography Monitoring) | p-value | Interpretation |
|---|---|---|---|---|
| Number of patients | 125 | 125 | – | Equal distribution |
| Mean age (years) | 39.6 ± 12.4 | 38.9 ± 11.7 | 0.614 | No significant difference |
| Sex distribution (M: F) | 22:103 | 23:102 | 0.678 | Female-dominant; balanced between groups |
| ASA physical status (I/II/III) | 35/58/32 | 37/55/33 | 0.921 | Comparable ASA classes |
| Type of surgery | | | | |
| Caesarean Section (CS) | 60 | 60 | – | Mean duration: 60 mins |
| Open Abdominal Myomectomy | 40 | 40 | – | Mean duration: 150 mins |
| Inguinal Hernia Repair | 25 | 25 | – | Mean duration: 45 mins |

**Table 2: Intraoperative respiratory and haemodynamic events**

| Outcome Measure | Group A (Standard Monitoring) | Group B (Capnography Monitoring) | p-value | Interpretation |
|---|---|---|---|---|
| Apnoea detection | Often missed | Identified in 98% of cases | – | Significantly improved with capnography. |
| Sedation-related respiratory depression | Not detected reliably | Consistently identified | – | Accurate $EtCO_2$ waveform monitoring |
| Time to detect desaturation | Delayed (>45 sec via $SpO_2$) | Early (~20 sec via $EtCO_2$) | – | Faster detection in the capnography group |
| Hypoxia ($SpO_2$ < 90%) | 12% (15/125) | 3% (4/125) | 0.003 | Significantly reduced |
| Desaturation (>5% $SpO_2$ drop) | 6% (8/125) | 1% (2/125) | 0.016 | Significant difference |
| Bradycardia (HR < 50 bpm) | 8% (10/125) | 2% (3/125) | 0.012 | Fewer events in the capnography group |
| Hypotension (SBP < 90 mmHg or >20% drop) | 20% (25/125) | 14% (18/125) | 0.213 | Not statistically significant |

**Table 3: Operative duration, satisfaction, and monitoring quality**

| Outcome Measure | Group A (Standard Monitoring) | Group B (Capnography Monitoring) | p-value | Interpretation |
|---|---|---|---|---|
| Mean operative duration (minutes) | 65 ± 10 | 63 ± 9 | 0.213 | No significant difference |
| Mean patient satisfaction score (Likert 1–5) | 3.9 ± 0.5 | 4.5 ± 0.4 | < 0.001 | Significantly higher in the capnography group |
| Monitoring Quality Index (MQI) score (0–10) | 5.2 ± 1.1 | 8.6 ± 0.9 | < 0.001 | Substantially higher quality of monitoring |

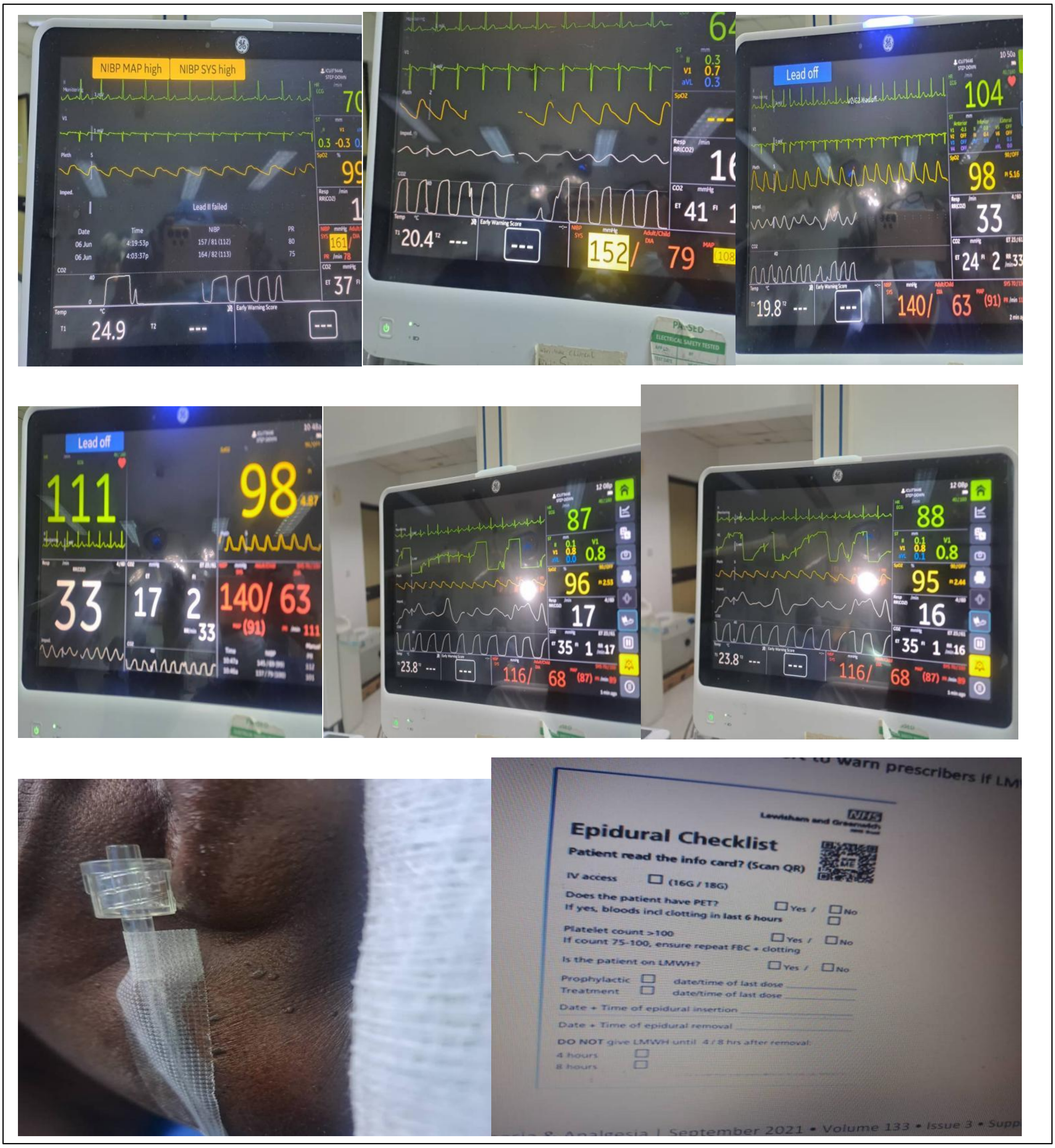


**Plate 1: Intraoperative monitor screenshots from the capnography group displaying continuous end-tidal $CO_2$ ($EtCO_2$) waveforms alongside oxygen saturation ($SpO_2$), heart rate (HR), and blood pressure (BP) parameters.**

## DISCUSSION

The results of this prospective randomised controlled trial provide compelling evidence that incorporating capnography into standard intraoperative monitoring during neuraxial anaesthesia significantly enhances the detection of respiratory compromise and improves patient-reported satisfaction. Capnography offers continuous, real-time assessment of ventilatory status, serving as a vital complement to conventional monitoring modalities such as pulse oximetry and non-invasive blood pressure. This multilayered approach enhances intraoperative vigilance, facilitates early identification of clinical deterioration, and supports timely intervention to mitigate adverse outcomes.

In the present study, a significant reduction in the incidence of hypoxia ($SpO_2 < 90\%$) was observed in the capnography group (3%) compared to the standard monitoring group (12%), with statistical significance ($p = 0.003$). This finding supports the usefulness of capnographic monitoring in promptly detecting respiratory events, even in spontaneously breathing patients under neuraxial block. The results confirm earlier work by Krauss and Hess, which demonstrated that capnography identified respiratory depression earlier than pulse oximetry during spinal anaesthesia with sedation, enabling a quicker clinical response.[10] Similarly, Weiniger et al. reported that $EtCO_2$ monitoring had superior sensitivity in detecting hypoventilation in parturients receiving intrathecal opioids during caesarean sections, highlighting capnography's value in regional anaesthesia settings.[11]

Bradycardia, defined as a heart rate below 50 beats per minute, was also significantly less frequent in the capnography group (2%) compared to the standard monitoring group (8%) ($p = 0.012$). Although bradycardia during neuraxial anaesthesia is often attributed to high spinal block or reduced venous return, it may also result from undetected hypoventilation, which can increase vagal tone. Somboonviboon et al. suggested that diminished respiratory effort, if left unrecognised, could worsen vagal responses, leading to bradyarrhythmia.[4] In our study, early detection of respiratory changes through $EtCO_2$ monitoring likely allowed for timely intervention before vagal-mediated bradycardia developed. Kodali further emphasised that capnography can act as a primary warning mechanism for ventilatory failure, often preceding measurable changes in pulse oximetry or blood pressure.

Desaturation events, defined as a more than 5% drop in $SpO_2$ from baseline, were also significantly lower in the capnography group (1%) compared to the standard group (6%) ($p = 0.016$). This finding aligns with the results of Langhan et al., who argued that pulse oximetry alone might not reliably detect early hypoventilation, particularly in non-intubated patients receiving supplementary oxygen.[12] Capnography, by contrast, provides immediate and dynamic information about the adequacy of ventilation, allowing for early intervention in response to subtle respiratory changes. Manifold et al. emphasised the importance of continuous waveform monitoring, especially for patients who are awake or lightly sedated, as overt clinical signs of respiratory compromise may be delayed or absent.[6]

Although the difference in hypotension between the groups—20% in the standard monitoring group compared to 14% in the capnography group did not reach statistical significance ($p = 0.213$), the observed trend suggests that enhanced ventilatory monitoring may play a crucial role in maintaining hemodynamic stability during procedures. Hutton et al. have highlighted that unrecognised respiratory-disturbances can trigger sympathetic or parasympathetic reflexes, which in turn can significantly influence blood pressure and heart rate by providing real-time feedback, end-tidal carbon dioxide ($EtCO_2$) monitoring equips anaesthetists with the vital information needed to make timely adjustments to patient positioning or fluid therapy, potentially averting episodes of hemodynamic deterioration that can complicate patient outcomes.[3]

In addition to the physiological benefits, the capnography group reported notably higher levels of patient satisfaction, evidenced by a mean satisfaction score of $4.5 \pm 0.4$, compared to $3.9 \pm 0.5$ in the standard group ($p < 0.001$). This increase in satisfaction levels may be attributed to greater patient confidence and a heightened sense of safety throughout the procedures. The visible presence of advanced monitoring technologies and the proactive attentiveness of the care team likely contribute to this reassuring environment. Conway et al. noted that patients undergoing sedation who were monitored using capnography experienced fewer respiratory events and expressed greater reassurance, indicating the psychological impact of such monitoring on patient experience.[7] Similarly, Saunders et al. emphasised the comfort provided by continuous monitoring, which is shown to significantly enhance the overall anaesthetic experience and foster trust in the quality and safety of care provided.[1]

Further supporting the clinical effectiveness of capnography, a recent meta-analysis conducted by Waugh et al. confirmed that the use of capnography significantly reduces the incidence of perioperative respiratory complications and improves overall clinical outcomes during regional anaesthesia procedures.[14] This evidence bolsters the case for incorporating capnography into routine practice. Moreover, during the COVID-19 pandemic, the heightened reliance on neuraxial anaesthesia underscored the pressing need for improved monitoring strategies, particularly for non-intubated patients. Uppal et al. highlighted the important role of capnography in delivering continuous respiratory assessment without increasing the risk of aerosol generation, thus significantly enhancing provider safety in resource-constrained environments where effective monitoring practices are crucial.[13]

In low- and middle-income countries (LMICs) such as Nigeria, where rapid escalation of care may be limited, the utility of capnography becomes even more pronounced. The World Health Organisation advocates the adoption of cost-effective safety measures such as capnography to reduce preventable intraoperative morbidity and mortality.[9] Likewise, the American Society of Anesthesiologists recommends capnographic monitoring as a standard of care wherever there is a risk of hypoventilation, even if patients appear clinically stable.[8] Our findings support the feasibility and impact of implementing capnography in LMIC settings to raise the standard of perioperative care.

Nonetheless, this study has limitations. Exclusion of patients with cardiopulmonary, neurological, or psychiatric comorbidities may reduce the generalisability of our results to higher-risk populations. Additionally, variability in institutional sedation practices may have influenced baseline respiratory drive, potentially affecting capnography's sensitivity in detecting events. Finally, the unblinded study design introduces a potential for observer bias, although the reliance on objective measurements such as $EtCO_2$ values, heart rate, and $SpO_2$ mitigates this risk.

## CONCLUSION

This study demonstrates that the integration of capnography into standard intraoperative monitoring significantly enhances the early detection of respiratory compromise and improves patient satisfaction during neuraxial anaesthesia in spontaneously breathing patients. The use of capnography enabled the timely identification of apnoea, sedation-related respiratory depression, and desaturation events that were often undetected by standard monitoring alone. Patients monitored with capnography experienced fewer episodes of hypoxia and bradycardia, indicating better intraoperative stability and improved perioperative safety.

Furthermore, the increased patient satisfaction observed in the capnography group underscores the value of visible and precise monitoring in reassuring conscious patients undergoing regional anaesthesia. These findings highlight the clinical benefit of adopting a multilayered monitoring strategy, especially in resource-limited settings where delayed recognition of respiratory compromise can have severe consequences. Given its feasibility, accuracy, and impact on safety, capnography should be considered a vital adjunct to routine monitoring during neuraxial anaesthesia. Wider implementation of capnographic monitoring, particularly in low- and middle-income countries, has the potential to reduce preventable perioperative complications and raise the standard of anaesthetic care.

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**Conflicts of interest**

There are no conflicts of interest.

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