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# COMPARATIVE ACCURACY OF SUMI HI-CAPNO FACEMASK AND SENTRI NASAL CANNULA FOR END-TIDAL CARBON DIOXIDE MONITORING IN SPONTANEOUSLY BREATHING PATIENTS UNDERGOING REGIONAL ANAESTHESIA

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## ABSTRACT

**Background:** Capnography provides continuous non-invasive assessment of ventilation and is useful for early detection of respiratory compromise in spontaneously breathing patients receiving supplemental oxygen. In non-intubated patients, the accuracy of end-tidal carbon dioxide ($EtCO_2$) monitoring may vary depending on the sampling interface. This study compared the Sumi Hi-Capno Facemask and the Sentri Nasal Cannula for $EtCO_2$ monitoring in spontaneously breathing adults undergoing regional anaesthesia.

**Materials & Methods:** This prospective comparative crossover study included 60 adult patients undergoing elective surgery under regional anaesthesia with spontaneous ventilation. $EtCO_2$ measurements were obtained sequentially using the Sumi Hi-Capno Facemask and the Sentri Nasal Cannula under identical clinical conditions. Arterial partial pressure of carbon dioxide ($PaCO_2$), measured by arterial blood gas analysis, was used as the reference standard. The primary outcome was comparison of mean $EtCO_2$ values between the two devices. Secondary outcomes included $PaCO_2$–$EtCO_2$ gradient, correlation with $PaCO_2$, Bland–Altman agreement, waveform quality, and clinical feasibility.

**Results:** The mean arterial $PaCO_2$ was 39.78 ± 2.91 mmHg. The mean $EtCO_2$ was 37.68 ± 3.34 mmHg with the Sumi Hi-Capno Facemask and 37.62 ± 3.01 mmHg with the Sentri Nasal Cannula, with no statistically significant difference between the two devices (P = 0.8355). The mean $PaCO_2$–$EtCO_2$ gradient was 2.10 ± 1.77 mmHg for the Sumi Hi-Capno Facemask and 2.16 ± 1.64 mmHg for the Sentri Nasal Cannula. Both devices showed strong correlation with arterial $PaCO_2$, with Pearson correlation coefficients of 0.8488 and 0.8467, respectively. Bland–Altman analysis showed comparable agreement with $PaCO_2$, and the direct inter-device mean bias was minimal at 0.0633 mmHg. Successful waveform acquisition was achieved in all patients.

**Discussion and conclusion:** The Sumi Hi-Capno Facemask and Sentri Nasal Cannula demonstrated comparable $EtCO_2$ measurement accuracy, $PaCO_2$ agreement, $PaCO_2$–$EtCO_2$ gradients, waveform reliability, and clinical feasibility in spontaneously breathing adults undergoing regional anaesthesia. Both commercial interfaces may be suitable for routine capnographic monitoring, with device selection guided by patient comfort, breathing pattern, procedural requirements, and institutional availability.

**KEYWORDS:**Capnography; End-tidal carbon dioxide; $EtCO_2$; $PaCO_2$; Sumi Hi-Capno Facemask; Sentri Nasal Cannula; Regional anaesthesia; Bland–Altman analysis.

## INTRODUCTION

End-tidal carbon dioxide ($EtCO_2$) monitoring is an important component of perioperative respiratory monitoring because it provides continuous, non-invasive assessment of ventilation in real time. Unlike pulse oximetry, which reflects oxygenation and may remain apparently normal during early hypoventilation in patients receiving supplemental oxygen, capnography detects changes in ventilation through both numerical $EtCO_2$ values and waveform morphology. This allows earlier recognition of respiratory depression, airway obstruction, apnoea, and ventilatory failure during anaesthesia and procedural sedation. (1–3)

Professional guidelines recommend capnographic monitoring during general anaesthesia and during moderate-to-deep sedation whenever feasible. Clinical studies have shown that capnography identifies respiratory compromise earlier than clinical observation or pulse oximetry alone, thereby allowing timely intervention before significant oxygen desaturation occurs. This is especially relevant in spontaneously breathing patients undergoing regional anaesthesia or procedural sedation, where supplemental oxygen is commonly administered and ventilatory compromise may otherwise be delayed in detection. (4–6)

In non-intubated patients, $EtCO_2$ monitoring depends not only on patient physiology but also on the design and positioning of the sampling interface. Reliable carbon dioxide sampling can be challenging because expired gas may be diluted by supplemental oxygen, affected by mouth breathing, altered by irregular respiratory patterns, or lost due to displacement of the sampling device. Therefore, the choice of interface is clinically important when capnography is used in spontaneously breathing patients. (7–9)

Commercially available interfaces for non-intubated capnography include dedicated capnography facemasks and nasal cannula-based systems. The Sumi Hi-Capno Facemask is designed to enable simultaneous oxygen delivery and sidestream carbon dioxide sampling through a face-mask interface. By covering the nose and mouth, such facemask-based systems may improve capture of expired gas from both nasal and oral breathing, but their performance may still be influenced by mask fit, oxygen flow, dead space, and patient movement. (8–10)

Nasal cannula-based capnography systems, such as the Sentri Nasal Cannula, are designed to provide oxygen delivery and carbon dioxide sampling through separate channels positioned near the nares. These systems are simple to apply and are generally well tolerated, but $EtCO_2$ accuracy may be affected when patients breathe predominantly through the mouth, when prongs are displaced, or when high oxygen flows dilute the sampled expired gas. Previous studies comparing different nasal cannula designs have demonstrated that interface configuration significantly influences carbon dioxide waveform reliability and $EtCO_2$ measurement accuracy. (7–9)

Although both facemask-based and nasal cannula-based commercial systems are used for $EtCO_2$ monitoring in spontaneously breathing patients, direct clinical comparison between these two interface types remains important. A facemask may offer broader expired gas capture from the nose and mouth, whereas a nasal cannula may offer greater simplicity and comfort. However, the extent to which these design differences influence $EtCO_2$ measurement accuracy, $PaCO_2$ agreement, waveform quality, and feasibility during regional anaesthesia requires systematic evaluation under identical clinical conditions. (8–11)

Arterial partial pressure of carbon dioxide ($PaCO_2$) remains the reference standard for carbon dioxide measurement. However, arterial blood gas analysis is intermittent and invasive, whereas $EtCO_2$ monitoring provides continuous trend information. In haemodynamically stable patients without major pulmonary pathology, $EtCO_2$ usually correlates with $PaCO_2$, although a small $PaCO_2$–$EtCO_2$ gradient is physiologically expected because of alveolar dead space and ventilation–perfusion variation. Therefore, validation of non-intubated $EtCO_2$ interfaces should include comparison with $PaCO_2$, assessment of the $PaCO_2$–$EtCO_2$ gradient, and agreement analysis. (12–14)

Method-comparison studies require more than correlation alone, because two methods may correlate strongly while still showing clinically relevant disagreement. Bland–Altman analysis is widely recommended to evaluate agreement between measurement methods by estimating mean bias and limits of agreement. In the context of capnography interface evaluation, this approach helps determine whether two monitoring systems provide clinically comparable $EtCO_2$ measurements. (13,14)

Therefore, the present prospective comparative crossover study was undertaken to compare the Sumi Hi-Capno Facemask and the Sentri Nasal Cannula for end-tidal carbon dioxide monitoring in spontaneously breathing adult patients undergoing regional anaesthesia. The study evaluated $EtCO_2$ measurement accuracy using arterial $PaCO_2$ as the reference standard, $PaCO_2$–$EtCO_2$ gradient, correlation with $PaCO_2$, Bland–Altman agreement, waveform quality, and clinical feasibility of both commercial monitoring interfaces.

## MATERIALS AND METHODS

### Study design and setting

This prospective comparative crossover study was conducted in the Department of Anaesthesiology, Saveetha Medical College and Hospital, Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai, India, over a period of one year after obtaining approval from the Institutional Ethics Committee. The Institutional Ethics Committee reference number was 013/11/2024/IEC/SMCH. Written informed consent was obtained from all study participants before enrolment. The study was conducted in accordance with accepted ethical principles for clinical research.

### Study participants

Adult patients aged 18–50 years with American Society of Anesthesiologists (ASA) physical status I or II who were scheduled to undergo elective surgery under regional anaesthesia and maintained spontaneous ventilation were consecutively recruited.

Patients with a history of smoking, bronchial asthma, chronic obstructive pulmonary disease, obstructive sleep apnoea, obesity, haemodynamic instability, sepsis, hypothermia, anticipated requirement for endotracheal intubation, intraoperative opioid administration, surgical duration of less than one hour, or refusal to participate were excluded from the study.

### Sample size estimation

The sample size was calculated based on a previous study evaluating end-tidal carbon dioxide measurements using non-intubated capnography interfaces in spontaneously breathing patients. The estimated minimum sample size was 55 participants. To compensate for possible dropouts and to improve the reliability of agreement analysis, 60 participants were included in the final study. Eligible patients were enrolled using consecutive sampling.

### Study devices

The first commercial device evaluated was the Sumi Hi-Capno Facemask (Life Tech India Pvt. Ltd., Chennai, Tamil Nadu, India), a disposable capnography facemask designed to permit simultaneous oxygen administration and sidestream end-tidal carbon dioxide sampling in spontaneously breathing patients.

The second commercial device evaluated was the Sentri Nasal Cannula,(Life Tech India Pvt. Ltd., Chennai, Tamil Nadu, India) a commercially available disposable dual-lumen nasal cannula designed for simultaneous oxygen delivery and sidestream carbon dioxide sampling. The nasal cannula interface delivers oxygen through one channel while expired carbon dioxide is sampled through a separate channel positioned near the nares.
Both devices were used according to their intended clinical purpose for non-intubated patients receiving supplemental oxygen and undergoing capnographic monitoring.

**Study procedure**
After successful administration of regional anaesthesia, patients were allowed to breathe spontaneously throughout the study period. Supplemental oxygen was administered at a flow rate of 5 L/min during monitoring. After a stabilization period of five minutes, an arterial blood sample was collected for arterial blood gas analysis to determine arterial partial pressure of carbon dioxide ($PaCO_2$).
Each participant underwent sequential end-tidal carbon dioxide monitoring using the Sumi Hi-Capno Facemask and the Sentri Nasal Cannula under identical clinical conditions. Oxygen flow rate, patient position, monitoring equipment, and intraoperative conditions were kept constant throughout the study period to minimise measurement variability. A two-minute washout interval was maintained between the two monitoring sessions.
For each device, $EtCO_2$ values were recorded at two-minute intervals over a ten-minute observation period, providing five consecutive readings per device. The mean of the five $EtCO_2$ readings obtained from each device was used for statistical analysis. Capnographic waveform quality, successful acquisition of interpretable $EtCO_2$ tracing, and practical feasibility of device use during regional anaesthesia were documented for each participant.

**Outcome measures**
The primary outcome was the comparison of mean end-tidal carbon dioxide values obtained using the Sumi Hi-Capno Facemask and the Sentri Nasal Cannula, using arterial $PaCO_2$ as the reference standard.
The secondary outcomes included $PaCO_2$–$EtCO_2$ gradient, correlation of each device with arterial $PaCO_2$, agreement between each device and arterial $PaCO_2$ assessed using Bland–Altman analysis, direct agreement between the two commercial devices, capnographic waveform quality, successful waveform acquisition, and clinical feasibility during regional anaesthesia.

**Statistical analysis**
Data were analysed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD), whereas categorical variables were presented as frequency and percentage. Normality of continuous variables was assessed using the Shapiro–Wilk test.
Paired Student's t-test was used to compare mean $EtCO_2$ values and $PaCO_2$–$EtCO_2$ gradients between the Sumi Hi-Capno Facemask and the Sentri Nasal Cannula. Pearson's correlation coefficient (r) was used to assess the relationship between $EtCO_2$ measurements and arterial $PaCO_2$. Agreement between $EtCO_2$ measurements and arterial $PaCO_2$, as well as direct agreement between the two commercial devices, was evaluated using Bland–Altman analysis with calculation of mean bias and 95% limits of agreement. A two-sided P value of $<0.05$ was considered statistically significant.

**RESULTS**
A total of 60 adult patients undergoing elective surgery under regional anaesthesia with spontaneous ventilation were included in the study. The baseline demographic and clinical characteristics of the participants are shown in Table 1. The mean age was 32.97 ± 7.90 years, and the mean body mass index was 24.32 ± 2.72 kg/m². The study population included 33 males (55.0%) and 27 females (45.0%). Equal proportions of patients belonged to ASA physical status I and II. The mean arterial $PaCO_2$ was 39.78 ± 2.91 mmHg.

**Table 1. Baseline demographic and clinical characteristics of the study participants (n = 60)**

| Characteristic | Value |
|---|---|
| Age (years), mean ± SD | 32.97 ± 7.90 |
| Age, median (range) | 33.0 (18–50) |
| Male, n (%) | 33 (55.0) |
| Female, n (%) | 27 (45.0) |
| Body mass index (kg/m²), mean ± SD | 24.32 ± 2.72 |
| Body mass index, median (range) | 24.60 (19.0–29.5) |
| Normal BMI, n (%) | 34 (56.7) |

| Characteristic | Value |
|---|---|
| Overweight, n (%) | 26 (43.3) |
| ASA physical status I, n (%) | 30 (50.0) |
| ASA physical status II, n (%) | 30 (50.0) |
| Pulse rate (beats/min), mean ± SD | 75.87 ± 7.60 |
| Systolic blood pressure (mmHg), mean ± SD | 120.67 ± 9.79 |
| Diastolic blood pressure (mmHg), mean ± SD | 79.50 ± 5.95 |
| Arterial $PaCO_2$ (mmHg), mean ± SD | 39.78 ± 2.91 |

Values are presented as mean ± standard deviation (SD), median (range), or number (percentage). BMI: body mass index; ASA: American Society of Anesthesiologists; $PaCO_2$: arterial partial pressure of carbon dioxide.

The mean $EtCO_2$ measured using the Sumi Hi-Capno Facemask was 37.68 ± 3.34 mmHg, while the corresponding value obtained using the Sentri Nasal Cannula was 37.62 ± 3.01 mmHg. Both devices recorded $EtCO_2$ values slightly lower than arterial $PaCO_2$, consistent with the expected physiological $PaCO_2$–$EtCO_2$ gradient. The mean $PaCO_2$–$EtCO_2$ gradient was 2.10 ± 1.77 mmHg for the Sumi Hi-Capno Facemask and 2.16 ± 1.64 mmHg for the Sentri Nasal Cannula. The paired difference in $EtCO_2$ values between the two devices was small and not statistically significant (P = 0.8355).

**Table 2. Comparison of $EtCO_2$ measurements and $PaCO_2$–$EtCO_2$ gradients between Sumi Hi-Capno Facemask and Sentri Nasal Cannula (n = 60)**

| Variable | Sumi Hi-Capno Facemask | Sentri Nasal Cannula | P value |
|---|---|---|---|
| Mean $EtCO_2$ (mmHg), mean ± SD | 37.68 ± 3.34 | 37.62 ± 3.01 | 0.8355 |
| Median $EtCO_2$ (mmHg) | 37.45 | 37.45 | — |
| $EtCO_2$ range (mmHg) | 31.0–43.3 | 31.6–45.0 | — |
| Mean $PaCO_2$–$EtCO_2$ gradient (mmHg), mean ± SD | 2.10 ± 1.77 | 2.16 ± 1.64 | — |
| Median gradient (mmHg) | 2.00 | 1.65 | — |
| Gradient range (mmHg) | −1.6 to 6.0 | −0.3 to 5.9 | — |
| Mean paired $EtCO_2$ difference: Sumi Hi-Capno Facemask vs Sentri Nasal Cannula (mmHg), mean ± SD | 0.06 ± 2.35 | — | |

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Values are presented as mean ± SD or median/range. Paired Student's t-test was used to compare mean $EtCO_2$ values between the two commercial devices. Gradient denotes $PaCO_2 - EtCO_2$. Positive values indicate $EtCO_2$ readings below arterial $PaCO_2$.

Both commercial devices demonstrated strong positive correlation with arterial $PaCO_2$. The Pearson correlation coefficient was 0.8488 for the Sumi Hi-Capno Facemask and 0.8467 for the Sentri Nasal Cannula. The inter-device correlation between the two commercial systems was also strong and statistically significant (r = 0.7297, P < 0.001), indicating that both devices tracked $EtCO_2$ variation in a similar manner across patients.

**Table 3. Correlation of $EtCO_2$ measurements with arterial $PaCO_2$ and inter-device correlation**

| Comparison | Pearson r | 95% CI lower | 95% CI upper | P value |
|---|---|---|---|---|
| Sumi Hi-Capno Facemask $EtCO_2$ vs arterial $PaCO_2$ | 0.8488 | 0.7583 | 0.9072 | <0.001 |
| Sentri Nasal Cannula $EtCO_2$ vs arterial $PaCO_2$ | 0.8467 | 0.7551 | 0.9059 | <0.001 |
| Sumi Hi-Capno Facemask $EtCO_2$ vs Sentri Nasal Cannula $EtCO_2$ | 0.7297 | 0.5839 | 0.8298 | <0.001 |

Pearson correlation coefficient was used to assess linear association. CI: confidence interval; $EtCO_2$: end-tidal carbon dioxide; $PaCO_2$: arterial partial pressure of carbon dioxide.

Bland–Altman analysis demonstrated acceptable agreement between both commercial devices and arterial $PaCO_2$. The Sumi Hi-Capno Facemask showed a mean bias of −2.10 mmHg with 95% limits of agreement from −5.56 to 1.36 mmHg.

The Sentri Nasal Cannula showed a mean bias of −2.16 mmHg with 95% limits of agreement from −5.38 to 1.06 mmHg. Direct comparison between the Sumi Hi-Capno Facemask and Sentri Nasal Cannula showed a minimal mean bias of 0.0633 mmHg, indicating no meaningful systematic difference between the two devices.

**Table 4. Bland–Altman agreement analysis of Sumi Hi-Capno Facemask and Sentri Nasal Cannula (n = 60)**

| Comparison | Mean bias (mmHg) | SD of difference | Lower limit of agreement | Upper limit of agreement |
|---|---|---|---|---|
| Sumi Hi-Capno Facemask vs arterial $PaCO_2$ | −2.0967 | 1.7656 | −5.5572 | 1.3639 |
| Sentri Nasal Cannula vs arterial $PaCO_2$ | −2.1600 | 1.6425 | −5.3792 | 1.0592 |
| Sumi Hi-Capno Facemask vs Sentri Nasal Cannula | 0.0633 | 2.3528 | −4.5481 | 4.6748 |

Bias was calculated as $EtCO_2$ − $PaCO_2$ for comparisons with arterial $PaCO_2$ and as Sumi Hi-Capno Facemask $EtCO_2$ − Sentri Nasal Cannula $EtCO_2$ for inter-device comparison. LoA: limits of agreement.
The $PaCO_2$–$EtCO_2$ gradient was within 5 mmHg in 57 patients (95.0%) using the Sumi Hi-Capno Facemask and in 57 patients (95.0%) using the Sentri Nasal Cannula. Gradients greater than 5 mmHg were observed in three patients (5.0%) with each device. A gradient within 2 mmHg was observed in 31 patients (51.7%) using the Sumi Hi-Capno Facemask and in 33 patients (55.0%) using the Sentri Nasal Cannula.

**Table 5. Clinical acceptability of $PaCO_2$–$EtCO_2$ gradients across the two commercial devices**

| Monitoring system | Gradient ≤2 mmHg, n (%) | Gradient ≤5 mmHg, n (%) | Gradient >5 mmHg, n (%) |
|---|---|---|---|
| Sumi Hi-Capno Facemask | 31 (51.7) | 57 (95.0) | 3 (5.0) |
| Sentri Nasal Cannula | 33 (55.0) | 57 (95.0) | 3 (5.0) |

Gradient thresholds of ≤2 mmHg and ≤5 mmHg were used as practical indicators of closeness to arterial $PaCO_2$.
Both commercial devices demonstrated good waveform reliability and clinical feasibility. Stable capnographic waveforms were obtained in 57 patients (95.0%) using the Sumi Hi-Capno Facemask and in 58 patients (96.7%) using the Sentri Nasal Cannula. Minor waveform dropouts were observed in three patients (5.0%) with the Sumi Hi-Capno Facemask and two patients (3.3%) with the Sentri Nasal Cannula. There was no statistically significant difference in waveform reliability between monitoring systems. Both devices were successfully used in all 60 patients without integration failure.

**Table 6. Waveform quality and clinical feasibility of Sumi Hi-Capno Facemask and Sentri Nasal Cannula (n = 60)**

| Parameter | Sumi Hi-Capno Facemask | Sentri Nasal Cannula |
|---|---|---|
| Successful capnographic waveform acquisition, n (%) | 60 (100.0) | 60 (100.0) |
| Stable waveform, n (%) | 57 (95.0) | 58 (96.7) |
| Minor waveform dropout, n (%) | 3 (5.0) | 2 (3.3) |
| Failure to obtain interpretable waveform, n (%) | 0 (0.0) | 0 (0.0) |
| Successful device use, n (%) | 60 (100.0) | 60 (100.0) |
| Failed device use, n (%) | 0 (0.0) | 0 (0.0) |
| Device-related complications, n (%) | 0 (0.0) | 0 (0.0) |
| Interface type | Disposable facemask | Disposable nasal cannula |

Values are presented as number (percentage).
Formal inferential testing was not performed for feasibility outcomes because both devices showed near-complete waveform acquisition and no device-use failure.

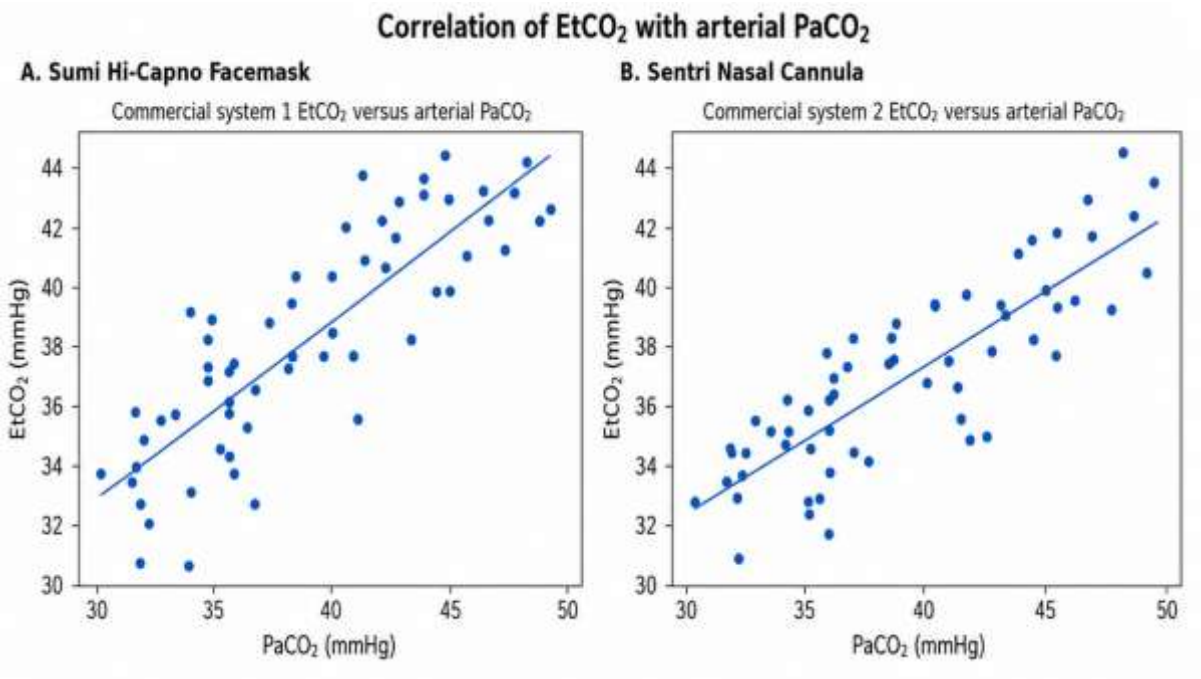


Figure 1. Correlation between end-tidal carbon dioxide ($EtCO_2$) measurements and arterial partial pressure of carbon dioxide ($PaCO_2$).
(A) Scatter plot demonstrating the correlation between $EtCO_2$ measured using the Sumi Hi-Capno Facemask and arterial $PaCO_2$.
(B) Scatter plot demonstrating the correlation between $EtCO_2$ measured using the Sentri Nasal Cannula and arterial $PaCO_2$. The solid line represents the linear regression line.

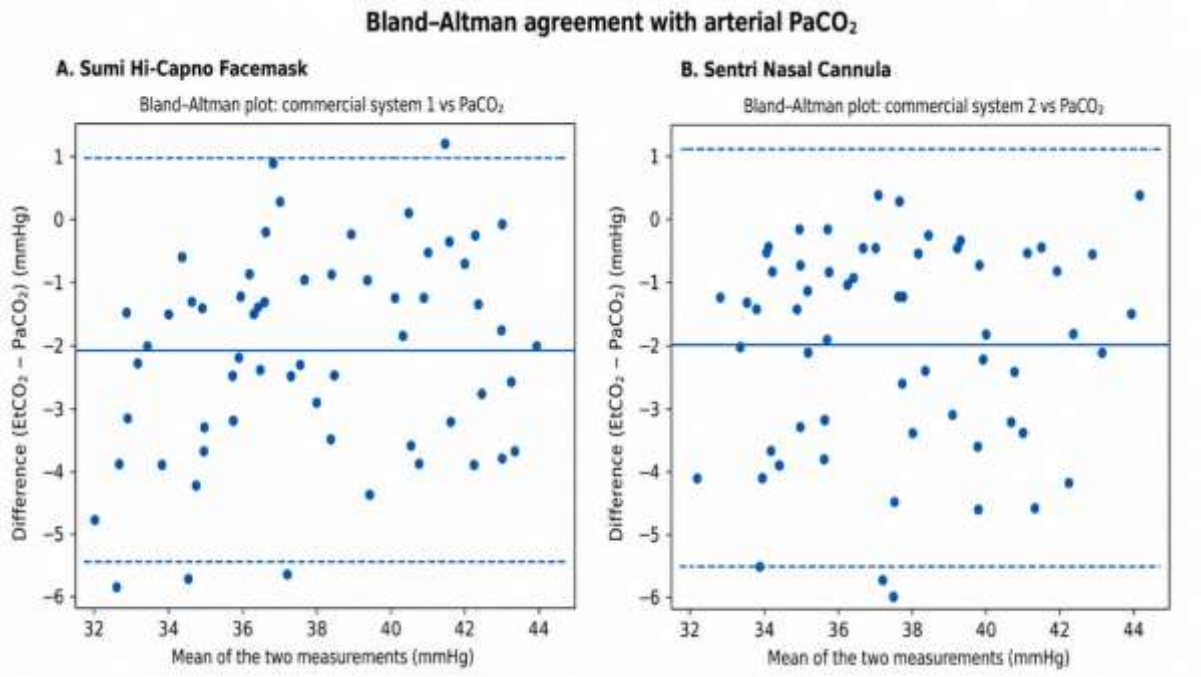


Figure 2. Bland–Altman analysis demonstrating agreement between end-tidal carbon dioxide ($EtCO_2$) measurements and arterial partial pressure of carbon dioxide ($PaCO_2$).
(A) Bland–Altman plot showing agreement between $EtCO_2$ measured using the Sumi Hi-Capno Facemask and arterial $PaCO_2$.
(B) Bland–Altman plot showing agreement between $EtCO_2$ measured using the Sentri Nasal Cannula and arterial $PaCO_2$. The central solid line represents the mean bias, and the dashed lines represent the 95% limits of agreement.

**DISCUSSION**

The present study demonstrated that the Sumi Hi-Capno Facemask and the Sentri Nasal Cannula provided comparable end-tidal carbon dioxide ($EtCO_2$) measurements in spontaneously breathing adult patients undergoing regional anaesthesia. The mean $EtCO_2$ values obtained with the two commercial interfaces were nearly identical, with no

statistically significant difference between devices. Both systems showed similar $PaCO_2$–$EtCO_2$ gradients, strong correlation with arterial $PaCO_2$, acceptable Bland–Altman agreement, reliable waveform acquisition, and complete clinical feasibility during intraoperative monitoring.

Continuous capnography is clinically important in spontaneously breathing patients because respiratory depression and airway obstruction may occur before oxygen desaturation becomes evident on pulse oximetry. This limitation is particularly relevant when supplemental oxygen is administered, as oxygen therapy may mask hypoventilation while carbon dioxide retention progresses. Previous clinical studies in procedural sedation have shown that capnography improves detection of ventilatory compromise and reduces hypoxaemic events compared with standard monitoring alone. (1–6,15–17)

In the present study, the Sumi Hi-Capno Facemask and Sentri Nasal Cannula produced similar mean $EtCO_2$ values, with a very small paired difference of 0.06 mmHg. This finding suggests that both commercial interfaces can provide comparable numerical $EtCO_2$ monitoring under controlled regional anaesthesia conditions. The similarity is clinically relevant because the two devices differ in design. The Sumi Hi-Capno Facemask samples expired carbon dioxide through a facemask interface that covers both the nose and mouth, whereas the Sentri Nasal Cannula samples expired gas near the nares while delivering oxygen through a separate channel. Interface design, sampling-port position, oxygen flow, mouth breathing, and device displacement are known to influence $EtCO_2$ accuracy in non-intubated patients. (7–10)

Both devices underestimated arterial $PaCO_2$ by a small margin, which is physiologically expected because $EtCO_2$ is usually lower than $PaCO_2$ due to alveolar dead space and ventilation–perfusion variation. The mean $PaCO_2$–$EtCO_2$ gradient was $2.10 \pm 1.77$ mmHg for the Sumi Hi-Capno Facemask and $2.16 \pm 1.64$ mmHg for the Sentri Nasal Cannula. These gradients are within the clinically acceptable range reported in stable spontaneously breathing patients and support the use of both interfaces for continuous ventilatory trend monitoring. However, $EtCO_2$ should not be considered a complete replacement for arterial blood gas analysis when precise $PaCO_2$ measurement is clinically required. (11,12)

The clinical acceptability analysis further supports the reliability of both devices. A $PaCO_2$–$EtCO_2$ gradient within 5 mmHg was observed in 57 patients (95.0%) with the Sumi Hi-Capno Facemask and in 57 patients (95.0%) with the Sentri Nasal Cannula. Only three patients in each device group had gradients greater than 5 mmHg. These findings indicate that, in most participants, both commercial interfaces provided $EtCO_2$ values close to arterial $PaCO_2$. This is important in routine regional anaesthesia, where continuous monitoring of ventilation trends is often more clinically useful than isolated intermittent carbon dioxide measurements.

Correlation analysis showed strong positive association between $EtCO_2$ and arterial $PaCO_2$ for both devices, with correlation coefficients of 0.8488 for the Sumi Hi-Capno Facemask and 0.8467 for the Sentri Nasal Cannula. The inter-device correlation was also strong. However, correlation alone does not prove that two devices can be used interchangeably, because two methods may correlate well while still showing clinically important differences. Therefore, Bland–Altman analysis is necessary in device-comparison studies to assess bias and limits of agreement. (13,14,18)

Bland–Altman analysis showed acceptable agreement between each commercial device and arterial $PaCO_2$. The Sumi Hi-Capno Facemask showed a mean bias of $-2.10$ mmHg, while the Sentri Nasal Cannula showed a mean bias of $-2.16$ mmHg. Direct comparison between the two commercial interfaces demonstrated a minimal mean bias of 0.0633 mmHg, indicating no meaningful systematic difference between them. The limits of agreement were also comparable. These findings suggest that both devices perform similarly for $EtCO_2$ estimation in stable adult patients undergoing regional anaesthesia.

Waveform reliability is an important component of capnographic monitoring because clinical interpretation depends not only on the $EtCO_2$ number but also on waveform morphology. A reliable waveform helps identify hypoventilation, apnoea, airway obstruction, rebreathing, and sampling-line problems. In the present study, successful capnographic waveform acquisition was achieved in all patients with both commercial devices. Stable waveforms were observed in 95.0% of patients using the Sumi Hi-Capno Facemask and 96.7% using the Sentri Nasal Cannula, with only minor waveform dropouts. This indicates that both interfaces were clinically practical and reliable during regional anaesthesia. (2,3,8)

Although both devices demonstrated comparable performance, their practical use may differ according to patient and procedural factors. A facemask-based system may be advantageous when oral breathing is prominent because it covers both the nose and mouth. However, mask fit and patient movement may influence sampling reliability. A nasal cannula system may be easier to apply and may be more comfortable for some patients, but mouth breathing and prong displacement may affect $EtCO_2$ capture. Therefore, the choice between the Sumi Hi-Capno Facemask and Sentri Nasal Cannula may depend on patient comfort, breathing pattern, procedural access, oxygen delivery requirements, and institutional availability.

The present study has some limitations. First, it was conducted at a single centre with 60 adult patients, which may limit generalisability. Second, only ASA physical status I and II patients undergoing elective surgery under regional anaesthesia were included; therefore, the findings may not apply to paediatric patients, obese patients, critically ill patients, or those with significant pulmonary disease. Third, the devices were assessed under controlled conditions with a fixed oxygen flow rate of 5 L/min, and performance under different oxygen flows, deeper sedation, emergency conditions, or predominant mouth breathing was not separately analysed. Fourth, although both commercial devices were clinically feasible, the study did not formally assess patient comfort, user preference, or cost-effectiveness.

Despite these limitations, the study provides useful comparative evidence for two commonly used commercial $EtCO_2$ monitoring interfaces. Both the Sumi Hi-Capno Facemask and Sentri Nasal Cannula demonstrated comparable $EtCO_2$ accuracy, $PaCO_2$ agreement, waveform reliability, and clinical feasibility. These findings suggest that either device may be used for capnographic monitoring in stable spontaneously breathing adult patients undergoing regional anaesthesia, with device selection guided by clinical context and availability.

## CONCLUSION

The Sumi Hi-Capno Facemask and Sentri Nasal Cannula demonstrated comparable end-tidal carbon dioxide measurement accuracy, $PaCO_2$ agreement, $PaCO_2$–$EtCO_2$ gradients, waveform reliability, and clinical feasibility in spontaneously breathing adult patients undergoing regional anaesthesia. Both devices showed strong correlation with arterial $PaCO_2$ and acceptable Bland–Altman agreement. The choice between these two commercial interfaces may therefore be guided by patient factors, breathing pattern, procedural requirements, comfort, and institutional availability.

**REFERENCES**


1. Bhavani-Shankar K, Moseley H, Kumar AY, Delph Y. Capnometry and anaesthesia. Can J Anaesth. 1992;39(6):617-632. doi:10.1007/BF03008330.
2. Kodali BS. Capnography outside the operating rooms. Anesthesiology. 2013;118(1):192-201. doi:10.1097/ALN.0b013e318278c8b6.
3. Krauss B, Hess DR. Capnography for procedural sedation and analgesia in the emergency department. Ann Emerg Med. 2007;50(2):172-181. doi:10.1016/j.annemergmed.2006.10.016.
4. American Society of Anesthesiologists. Standards for Basic Anesthetic Monitoring [Internet]. Schaumburg (IL): American Society of Anesthesiologists; 2025 [cited 2026 Jul 5]. Available from: https://www.asahq.org/standards-and-practice-parameters/standards-for-basic-anesthetic-monitoring
5. Burton JH, Harrah JD, Germann CA, Dillon DC. Does end-tidal carbon dioxide monitoring detect respiratory events prior to current sedation monitoring practices? Acad Emerg Med. 2006;13(5):500-504. doi:10.1197/j.aem.2005.12.017.
6. Lightdale JR, Goldmann DA, Feldman HA, Newburg AR, DiNardo JA, Fox VL. Microstream capnography improves patient monitoring during moderate sedation: a randomized, controlled trial. Pediatrics. 2006;117(6):e1170-e1178. doi:10.1542/peds.2005-1709.
7. Yanagidate F, Dohi S. Modified nasal cannula for simultaneous oxygen delivery and end-tidal $CO_2$ monitoring during spontaneous breathing. Eur J Anaesthesiol. 2006;23(3):257-260. doi:10.1017/S0265021505002279.
8. Ebert TJ, Novalija J, Uhrich TD, Barney JA. The effectiveness of oxygen delivery and reliability of carbon dioxide waveforms: a crossover comparison of 4 nasal cannulae. Anesth Analg. 2015;120(2):342-348. doi:10.1213/ANE.0000000000000537.
9. Arakawa H, Kaise M, Sumiyama K, Saito S, Suzuki T, Tajiri H. Does pulse oximetry accurately monitor a patient's ventilation during sedated endoscopy under oxygen supplementation? Singapore Med J. 2013;54(4):212-215. doi:10.11622/smedj.2013075.
10. Yoon SZ, Lee SI, Lim HJ, Yoon SM. Clinical availability of end-tidal carbon dioxide monitoring using a nasal cannula in non-intubated patients. Yonsei Med J. 2014;55(3):817-822. doi:10.3349/ymj.2014.55.3.817.
11. Takano Y, Sakamoto O, Kiyofuji C, Ito K. A comparison of the end-tidal $CO_2$ measured by portable capnometer and the arterial $PCO_2$ in spontaneously breathing patients. Respir Med. 2003;97(5):476-481. doi:10.1053/rmed.2002.1468.
12. McSwain SD, Hamel DS, Smith PB, Gentile MA, Srinivasan S, Meliones JN, et al. End-tidal and arterial carbon dioxide measurements correlate across all levels of physiologic dead space. Respir Care. 2010;55(3):288-293.
13. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;1(8476):307-310.
14. Giavarina D. Understanding Bland Altman analysis. Biochem Med (Zagreb). 2015;25(2):141-151. doi:10.11613/BM.2015.015.
15. Qadeer MA, Vargo JJ, Dumot JA, Lopez R, Trolli PA, Stevens T, et al. Capnographic monitoring of respiratory activity improves safety of sedation for endoscopic cholangiopancreatography and ultrasonography. Gastroenterology. 2009;136(5):1568-1576. doi:10.1053/j.gastro.2009.02.004.
16. Deitch K, Miner J, Chudnofsky CR, Dominici P, Latta D. Does end tidal $CO_2$ monitoring during emergency department procedural sedation and analgesia with propofol decrease the incidence of hypoxic events? A randomized, controlled trial. Ann Emerg Med. 2010;55(3):258-264. doi:10.1016/j.annemergmed.2009.07.030.
17. Wang CY, Ling LC, Cardosa MS, et al. Capnography monitoring improves safety of procedural sedation: a systematic review and meta-analysis. J Clin Monit Comput. 2020;34(5):895-904. doi:10.1007/s10877-019-00375-4.
18. Schober P, Boer C, Schwarte LA. Correlation coefficients: appropriate use and interpretation. Anesth Analg. 2018;126(5):1763-1768. doi:10.1213/ANE.0000000000002864.