



Accuracy of Respiratory Rate Monitoring Using Thammasat Capnoline During Total Intravenous Anesthesia: a Modified Oxygen Nasal Cannula-Based Capnometry Device

Sukhumakorn Worathongchai^{1,*}, Siriwan Tatiyanupunwong¹,
Piyaporn Nambuddee¹, Thapawee Likhitkarnpaiboon²

¹*Department of Anesthesia, Faculty of Medicine, Thammasat University,
Pathum Thani 12120, Thailand*

²*Anesthetist Nursing Department, Thammasat University Hospital, Pathum Thani 12120, Thailand*

Received 15 January 2025; Received in revised form 23 May 2025

Accepted 23 June 2025; Available online 17 December 2025

ABSTRACT

Continuous respiratory monitoring is crucial for patients receiving total intravenous anesthesia (TIVA), as respiratory depression such as hypoventilation and apnea can be difficult to detect. Capnometry via nasal cannula offers a cost-effective method for continuous end-tidal carbon dioxide (ETCO₂) monitoring. This study evaluated the correlation between respiratory rates measured by the Thammasat Capnoline device and clinical assessment during TIVA with supplemental oxygen. A prospective observational study was conducted on 63 patients (aged 18–65 years, ASA I–III) undergoing procedures under TIVA. Respiratory rates were simultaneously measured using thoracoabdominal observation and capnometry at various oxygen flow rates. The participants (38.10% male) had a mean age of 40.62 years and mean BMI of 23.46 kg/m², with ASA I (55.56%), II (42.86%), and III (1.59%). Mean respiratory rates (breaths/min) showed no significant difference between methods across oxygen flow rates: 2 L/min (17.12 vs 17.39, $p = 0.119$), 3 L/min (17.35 vs 17.49, $p = 0.455$), 4 L/min (17.32 vs 17.31, $p = 0.929$), and 5 L/min (17.69 vs 17.69, $p = 0.998$). Oxygen flow variation did not affect accuracy ($p = 0.901$). Thus, Thammasat Capnoline provides reliable respiratory monitoring comparable to clinical assessment during TIVA.

Keywords: Capnoline; End-tidal carbon dioxide; Intravenous anesthesia; Nasal oxygen cannula; Respiratory rate

1. Introduction

Hypoventilation, apnea, and airway obstruction are common complications during procedural sedation under total intravenous anesthesia (TIVA) and often require oxygen supplementation [1]. While pulse oximetry provides reliable monitoring of oxygenation, it may exhibit delayed detection of respiratory depression, particularly in patients receiving supplemental oxygen [2].

Electrical impedance respiratory rate monitoring is a well-established technique, but it can have technical limitations, which may vary depending on the surgical site. Furthermore, thoracic wall movement can persist in the presence of airway obstruction, which creates a false-negative interpretation by an impedance monitor as “breathing” [2]. Respiratory rate can be monitored continuously by thoracic impedance pneumography which measures changes in electrical impedance associated with chest movement during respiration. However, many factors, including inaccurate ECG electrode placement, motion artifact, and physiological events unrelated to respiration that cause chest wall movement (such as coughing and crying), may generate false alarms due to inaccurate readings. Insensitivity to airway obstruction or apnea, which presents with chest wall movement without any actual gas exchange, is another significant limitation of impedance pneumography [3]. Apnea alarms occurred with the false fraction being 28% from thoracic impedance; furthermore, the impedance sensor failed to detect apnea on at least six occasions during a mean observation period of 101 minutes per patient [13].

Continuous end-tidal carbon dioxide (ETCO₂) monitoring via capnometry facilitates early detection of cardiorespiratory perturbations during anesthesia [3].

ETCO₂ monitoring during moderate and deep sedation by intravenous anesthesia is one noninvasive respiratory monitoring method. Nasal cannula-based sampling is the most convenient and may also be the most cost-effective approach for ETCO₂ monitoring [4]. However, in spontaneously breathing, non-intubated patients, sampling ETCO₂ through a nasal cannula is potentially problematic due to the mixing of expired gas with ambient air. This can lead to inaccurate measurements, resulting in erroneous low values when compared to measurements obtained from a closed system with minimal dead space (e.g., mask or endotracheal tube) [5].

The anesthesia department at Thammasat University Hospital uses carbon dioxide side stream sampling lines that are device-specific and equipped with screw-head connectors. These devices are not adaptable to the facial contours, may slip easily, and require fixation with adhesive tape on the patient’s face. Moreover, a standard carbon dioxide sampling set with an oxygen cannula is costly, must be imported, and is compatible only with a specific capnometry device. Therefore, we developed the Thammasat Capnoline (Modified Oxygen Nasal Cannula-Based Capnometry Device). This modified device integrates oxygen delivery and ETCO₂ sampling for spontaneously breathing patients undergoing TIVA to provide ETCO₂ monitoring and respiratory rate measurement during procedural sedation or operation, and may offer accuracy comparable to standard clinical measurements.

This study aimed to compare respiratory rate assessment by capnometry using Thammasat Capnoline with clinical measurement (used as the reference method) in spontaneously breathing patients during procedural sedation or operation under to-

tal intravenous anesthesia. The secondary goal was to determine whether variations in oxygen flow rate affected the accuracy of capnometry in assessing respiratory rate.

2. Materials and Methods

This prospective observational study was conducted at Thammasat University Hospital, Pathum Thani, Thailand. The Human Research Ethics Committee of Thammasat University No.1 (Faculty of Medicine) approved the study protocol (Certificate of Approval Number 108/2020) and informed consent was obtained from all participants.

The primary outcome was the mean difference in respiratory rate measurement by capnometry compared with standard clinical measurement. The secondary outcome was the influence of different oxygen flow rates on the accuracy of respiratory rate assessment using Thammasat Capnoline. Episodes of apnea or arterial desaturation were also recorded.

The Thammasat Capnoline model was designed with a nasal cannula to capture expiratory flow from nasal exhaled gas by utilizing an empty 10-mL sterile water ampule (Fig. 1). The ampule was divided into three sections in horizontal orientation, with the mid-lower part and bilateral distal portions removed using sterile surgical scalpel blades No. 11 to allow for attachment to the nasal cannula (Fig. 2). Finally, the cork of the Thammasat Capnoline was connected to a side-stream sampling line for ET CO_2 measurement (Fig. 3) to prevent dislodgement of the sampling line.

We recruited 63 patients who were scheduled to undergo procedural sedation or surgery under total intravenous anesthesia, aged 18-65 years with ASA physical status classification I-III. Exclusion criteria were patient refusal, inability to pro-

vide written informed consent, obesity (defined by a body mass index more than 30 kg/m²), history or high risk of obstructive sleep apnea or OSA (patients were screened using the STOP-BANG questionnaire for screening sleep apnea; those with a score of 3 or more were excluded), pregnancy, patient with severe pulmonary disease (e.g., uncontrolled asthma or chronic obstructive pulmonary disease), and bilateral nasal obstruction. Therefore, patients considered at risk for perioperative respiratory dysfunction were excluded from the study.

All patients were continuously monitored using pulse oximetry and three-lead electrocardiography in automatic mode via a multiparameter monitor. The Thammasat Capnoline was designed to administer nasal oxygen and sample exhaled gas for ET CO_2 measurement using a side-stream capnometer (GE CARESCAPETM B650 Patient Monitor with CO_2 module). The capnometer was calibrated prior to each series of measurements. Respiratory rate was also assessed using both the Thammasat Capnoline and clinical observation. Clinical measurement was performed before recording the displayed values from the capnometer. Data were recorded three minutes after a normal, stable capnography waveform was observed. Respiratory rate was measured by counting chest wall movement for one minute, the values displayed by the capnometer were simultaneously recorded. A set of measurements was obtained for each patient receiving supplemental oxygen at four different flow rates: 2, 3, 4, and 5 L/min. For each supplemental oxygen flow rate, the rate was maintained for three minutes, and respiratory rate determinations were recorded after each one-minute interval. Episodes of apnea, defined as an absence of chest wall movement and respiratory rate of 0 breaths per minute from

capnometry lasting more than 30 seconds, were recorded.



Fig. 1. Materials used for constructing the Thammasat Capnoline.



Fig. 2. The Thammasat Capnoline.



Fig. 3. Side-stream line for ETCO₂ measurement.

2.1 Statistical analysis

The sample size was calculated using the estimate sample size for a one-sample

comparison of mean to hypothesis value. Under the hypothesis that the mean difference in respiratory rate measurement by capnometry compared with standard (clinical measurement in one minute) was 2.2 from the study of Gaucher. et al [3]. The standard deviation (SD) from the study of Goudra et al. was 5.9 and the mean difference was 0.4 [6]. A one-sided test was assigned with type 1 error at 5% and power of 80% (alpha 0.05, power 0.8). This was calculated using computer programs and determined to be 57. An additional 10% was included to account for subject withdrawal or rejection (dropout) during the study. The total sample size in this study was 63 participants.

Clinical assessment of respiratory rate was considered the reference method, with capnometry serving as the comparative method. All data were analyzed using SPSS software version 27. Continuous variables are presented as mean \pm SD for normally distributed data, or as median with interquartile range (IQR) for non-normally distributed data. Categorical variables are presented as frequencies with corresponding percentages. Respiratory rates obtained from each method were normalized by adjusting for each individual's mean respiratory rate at each oxygen flow rate, and comparisons were performed using the paired t-test. The effect of supplemental oxygen flow rate on the accuracy of capnometry-derived respiratory rates was evaluated. As the data were not normally distributed, the Friedman test was applied. A *P*-value of < 0.05 was considered statistically significant.

3. Results and Discussion

Sixty-three patients were enrolled in the study and completed the study. The demographic characteristics of all participants

including gender, age, body weight, height, BMI, and ASA physical status classifications, are presented in Table 1. The Thammasat Capnoline was well tolerated in all patients. Respiratory rates were easily assessed even in patients receiving different oxygen flow rates. No episodes of apnea or arterial desaturation occurred during the study period.

Table 1. Patient characteristics.

Patient Characteristics	
Gender n (%)	
-Male	24 (38.10)
-Female	39 (61.90)
Age; years	40.62 (13.97); 19-64
Weight; kg	61.97 (11.65); 40-91
	161.83 (8.33);
Height; cm	
	145-183
BMI; kg/m²	23.46 (3.85); 16-32.8
ASA physical status, n (%)	
I	35 (55.56)
II	27 (42.86)
III	1 (1.59)
Intraoperative complications, n (%)	
Yes	0 (0.00)
No	63 (100)

Note: Data are presented as mean (SD); range, unless otherwise specified.

Compared with the clinical reference method, there was no statistically significant difference in respiratory rate measurements between clinical assessment and the Thammasat Capnoline. Mean respiratory rate (breaths per minute) for clinical measurement and the Thammasat Capnoline were 17.12±3.18 vs 17.39±3.38 at 2 L/min oxygen flow, 17.35±3.05 vs 17.49±3.49 at 3 L/min, 17.32±2.86 vs 17.31±2.91 at 4 L/min, and 17.69±3.09 vs 17.69±3.32 at 5 L/min. (*P*-values were 0.119, 0.455, 0.929, and 0.998, respectively) (Table 2). In addition, the accuracy of respiratory rate assessment using the Thammasat Capnoline was not influenced by different oxygen flow rates (*P*-value = 0.901) (Table 3).

Table 2. Comparison of respiratory rate measurement between clinical measurement and the Thammasat Capnoline.

Oxygen flow rates (L/min)	Clinical Measurement	Thammasat Capnoline	<i>P</i> -value
	RR (mean±SD)	RR (mean±SD)	
2	17.12±3.18	17.39±3.38	0.119
3	17.35±3.05	17.49±3.49	0.455
4	17.32±2.86	17.31±2.91	0.929
5	17.69±3.09	17.69±3.32	0.998

Note: RR stands for respiratory rate

Table 3. Comparison respiratory rate measurement by the Thammasat Capnoline according to the value of supplemental oxygen flow rate.

Oxygen flow rate (L/min)	RR; Median (IQR)	<i>P</i> -value
2	17.33 (4)	
3	17.67 (4)	
4	17.67 (3.33)	0.901
5	18 (3.33)	

Note: RR stands for respiratory rate

3.1 Discussion

In spontaneously breathing patients undergoing procedural sedation or surgery under total intravenous anesthesia, continuous respiratory rate assessment using the Thammasat Capnoline demonstrated high accuracy, comparable to clinical assessments. Additionally, delivering supplemental oxygen at different flow rates did not affect respiratory rate measurement.

Arterial desaturation detection by pulse oximetry may delay the diagnosis of hypoventilation, especially in patients who received supplemental oxygen [7]. Thoracic impedance pneumography has been used for respiratory rate measurement [8-10]; however, it has certain limitations, particularly when the surgical site restricts the area available for sensor placement. Additionally, thoracic wall movement can still occur despite upper airway obstruction, potentially leading to inaccurate readings [11-13]. Continuous capnometry monitoring was previously used in intubated patients; however, more recently, nasal oxygen canulae have been developed to measure res-

piratory rate and detect apnea episodes in spontaneously breathing patients who require supplemental oxygen. Several studies reported that, compared to other devices, capnometry detected impaired airway function 5-240 seconds earlier than pulse oximetry [14, 15].

Previous studies provide important context for our findings. Fukuda et al. examined the reliability of ETCO_2 measurements via nasal cannula and found that device design significantly influences accuracy [16]. Restrepo et al. highlighted that compatibility between capnography sampling lines and portable bedside capnography monitors is crucial for reliable respiratory monitoring, emphasizing the need for proper validation of components [17]. Mason et al. demonstrated the feasibility of low-flow side-stream capnography systems with extended nasal cannulae in pediatric patients, supporting the flexibility and adaptability of capnometry setups in various scenarios [18]. The Thammasat Capnoline aligns with these findings, demonstrating that thoughtful design and validation can yield reliable respiratory monitoring solutions. Additionally, cost may limit the widespread use of commercial nasal capnometry devices. The Thammasat Capnoline is likely to have greater cost-effectiveness because it uses locally available materials and a simplified design, making it a more affordable option without compromising accuracy or reliability. This affordability broadens its potential applicability, especially in resource-limited health-care settings.

Our study had some limitations. First, data collection was not blinded. However, clinical measurements were performed prior to recording the displayed values; therefore, the impact of unblinded collection on the results may have been lim-

ited. Second, the risk of carbon dioxide re-breathing during low-flow oxygen delivery rates was not evaluated. Finally, the validity of the measured end-tidal carbon dioxide values was not assessed because the primary purpose of monitoring end-tidal carbon dioxide in sedated patients with spontaneous breathing was to detect respiratory depression or apnea. Future research should continue to explore compatibility issues, biological variability, and device adaptability in high-risk and pediatric populations.

4. Conclusion

We found that the Thammasat Capnoline (Modified Oxygen Nasal Cannula-Based Capnometry Device) provides accurate and cost-effective continuous respiratory monitoring in patients receiving supplemental oxygen during total intravenous anesthesia (TIVA) for procedural sedation. The device maintained its accuracy across varying supplemental oxygen flow rates and may serve as a reliable alternative to clinical assessment alone.

References

- [1] 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):257–60.
- [2] Soto RG, Fu ES, Vila H Jr, Miguel RV. Capnography accurately detects apnea during monitored anesthesia care. *Anesth Analg.* 2004;99(2):379–82.
- [3] Gaucher A, Frasca D, Minoz O, Debaene B. Accuracy of respiratory rate monitoring by capnometry using the Capnomask[®] in extubated patients receiving supplemental oxygen after surgery. *Br J Anaesth.* 2012;108(2):316–20.
- [4] Ebert TJ, Novalija J, Uhrich TD, Barney JA. The effectiveness of oxygen

- delivery and reliability of carbon dioxide waveforms: a crossover comparison of four nasal cannulae. *Anesth Analg.* 2015;120(2):342–8.
- [5] Kasuya Y, Akça O, Sessler DI, Ozaki M, Komatsu R. Accuracy of postoperative end-tidal PCO₂ measurements with mainstream and sidestream capnography in non-obese patients and in obese patients with and without obstructive sleep apnea. *Anesthesiology.* 2009;111(3):609–15.
- [6] Goudra BG, Penugonda LC, Speck RM, Sinha AC. Comparison of acoustic respiration rate, impedance pneumography and capnometry monitors for respiration rate accuracy and apnea detection during GI endoscopy anesthesia. *Open J Anesthesiol.* 2013;3(2):74–9. doi:10.4236/ojanes.2013.32019.
- [7] Pedersen T, Nicholson A, Hovhannisyan K, Møller AM, Smith AF, Lewis SR. Pulse oximetry for perioperative monitoring. *Cochrane Database Syst Rev.* 2014;2014(3):CD002013. doi:10.1002/14651858.CD002013.pub3.
- [8] Coates AL, Vallinis P, Mullahoo K, Seddon P, Davis GM. Pulmonary impedance as an index of severity and mechanisms of neonatal lung disease. *Pediatr Pulmonol.* 1994;17(1):41–9.
- [9] Haborne D. Measuring respiratory rate [comment]. *Arch Emerg Med.* 1992;9(4):377–8.
- [10] Freundlich JJ, Erickson JC. Electrical impedance pneumography for simple nonrestrictive continuous monitoring of respiratory rate, rhythm and tidal volume for surgical patients. *Chest.* 1974;65(2):181–4.
- [11] Davidson JA, Hosie HE. Limitations of pulse oximetry: respiratory insufficiency—a failure of detection [case reports]. *BMJ.* 1993;307(6900):372–3.
- [12] Hutton P, Clutton-Brock T. The benefits and pitfalls of pulse oximetry [editorial]. *BMJ.* 1993;307(6902):457–8.
- [13] Wiklund L, Hök B, Ståhl K, Jordeby-Jönsson A. Postanesthesia monitoring revisited: frequency of true and false alarms from different monitoring devices. *J Clin Anesth.* 1994;6(3):182–8.
- [14] 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):500–4.
- [15] Deitch K, Miner J, Chudnofsky CR, Dominici P, Latta D. Does end-tidal CO₂ 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):258–64.
- [16] Fukuda K, Ichinohe T, Kaneko Y. Is measurement of end-tidal CO₂ through a nasal cannula reliable? *Anesth Prog.* 1997;44(1):23–6.
- [17] Restrepo RD, Karpenkop I, Liu KE. Evaluation of capnography sampling line compatibility and accuracy when used with a portable capnography monitor. *J Vis Exp.* 2020;(163):e61670. doi:10.3791/61670.
- [18] Mason KP, Burrows PE, Dorsey MM, Zurakowski D, Krauss B. Accuracy of capnography with a 30-foot nasal cannula for monitoring respiratory rate and end-tidal CO₂ in children. *J Clin Monit Comput.* 2000;16(4):259–62.