


REVIEW

Open Access



Seeing beyond the numbers: capnography as a vital tool in pediatric emergency care

Shree Rath¹ , Mohammed Alsabri^{2,3*} , Abdelrahman M. Tawfik⁴, Eman Makky⁴, Muhammad Azan Shahid⁵, Ebraheem A. Ebraheem⁶, Alaa Zayed⁷ and Israa Magdy Ata⁸

Abstract

Purpose End-tidal carbon dioxide (ETCO₂) monitoring is a vital, noninvasive technique for assessing ventilation, circulatory status, and predicting adverse events in pediatric emergency departments (EDs). This review aims to synthesize current evidence, examine barriers, and highlight strategies to optimize ETCO₂ monitoring in pediatric emergency settings.

Methods A narrative review of the literature was conducted, encompassing epidemiological data, clinical guidelines, expert consensus statements, and recent studies targeting ETCO₂ monitoring in pediatric emergencies. Key topics evaluated include physiological principles, airway management, prognostic value in cardiac arrest, procedural sedation safety, sepsis triage, limitations, and future directions. Data from both high- and low-resource settings were included.

Results ETCO₂ monitoring demonstrates high sensitivity and specificity for confirming endotracheal tube placement and early detection of respiratory compromise—identifying hypoventilation, apnea, and airway obstruction minutes before pulse oximetry. During CPR, persistently low ETCO₂ values correlate with poor outcomes, while sudden increases signal return of spontaneous circulation. In procedural sedation, routine capnography reduces hypoxic episodes and adverse events. In sepsis, ETCO₂ inversely correlates with lactate levels, offering a rapid, non-invasive marker of perfusion, though its reliability diminishes in multisystemic shock. Challenges include equipment limitations, provider training gaps, lack of universal protocols, and cost barriers—especially in low-resource settings.

Conclusion ETCO₂ monitoring is an essential tool in pediatric emergency care, enhancing safety and clinical decision-making across multiple scenarios. Addressing implementation barriers through education, standardized protocols, and accessible technology is crucial to ensure widespread adoption and improved outcomes for critically ill children.

Keywords ETCO₂, Pediatrics, Critical care, Procedural sedation, Oximetry

*Correspondence:

Mohammed Alsabri
Alsabri5000@gmail.com

¹All India Institute of Medical Sciences Bhubaneswar, Bhubaneswar, India

²Emergency Department, Althawara Modern General Hospital, Sanaa, Yemen

³Pediatric Emergency Department, Department of Pediatrics, St. Christopher's Hospital for Children, Philadelphia, PA, USA

⁴Faculty of Medicine, Alexandria University, Alexandria, Egypt

⁵Brooklyn College, CUNY, NY, USA

⁶Sahel Teaching Hospital, Egyptian Ministry of Health, Cairo, Egypt

⁷Department of Medicine, Faculty of Medicine and Health Sciences, An-Najah National University, Nablus, Palestine

⁸Faculty of Medicine, Menofia University, Menofia, Egypt



© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

Introduction

End-tidal carbon dioxide (ETCO₂) monitoring has undergone a remarkable transformation over the past three decades. Once confined to the operating room, it is now recognized as a vital tool across pediatric emergency and critical care settings. Its clinical relevance lies not only in providing a numeric estimate of ventilation and perfusion but also in the rich information contained within waveform morphology, offering insights into airway patency, respiratory mechanics, and circulatory status. In children, where physiologic reserve is limited and clinical deterioration can be rapid, such continuous, non-invasive feedback is especially valuable [1].

Several authoritative guidelines now highlight the central role of ETCO₂. The 2020 American Heart Association (AHA) Pediatric Life Support guidelines recommend waveform capnography as the standard for confirming tracheal intubation and for monitoring the quality of cardiopulmonary resuscitation (CPR) and recognition of return of spontaneous circulation (ROSC) [2]. Similarly, the American Academy of Pediatrics (AAP) 2019 sedation guideline endorses capnography as an adjunct to pulse oximetry during moderate and deep sedation, emphasizing its ability to detect respiratory depression earlier than oxygen desaturation [3]. The Project for Universal Management of Airways (PUMA) consensus expands this view globally, identifying waveform capnography as the gold standard for confirming endotracheal placement and for preventing unrecognized esophageal intubation across perioperative and emergency contexts [4]. Most recently, the International Liaison Committee on Resuscitation (ILCOR) 2023 statements highlight ETCO₂ as a useful indicator of CPR quality and perfusion, while acknowledging uncertainty regarding its role in guiding resuscitation termination in children [5].

Yet, despite these endorsements, ETCO₂ remains underutilized in pediatric emergency departments (PEDs) [6]. Pediatric evidence is strongest in airway confirmation and sedation but is emerging in trauma, sepsis, and transport medicine [7]. Furthermore, clinicians often focus on absolute values while underappreciating waveform interpretation, even though abnormal patterns can signal obstructive physiology, rebreathing, or early ROSC [8, 9].

In this narrative review, we synthesize current evidence on the use of ETCO₂ in pediatric emergency care. We cover its established roles in airway management, CPR and ROSC detection, and procedural sedation, as well as its growing utility in shock and sepsis, trauma and prehospital care, neonatal/infant contexts, and global health implementation. Our aim is to provide clinicians with a practical, evidence-based framework for integrating ETCO₂ into everyday pediatric emergency practice worldwide.

Physiology and principles of ETCO₂ monitoring

Monitoring end-tidal carbon dioxide (ETCO₂) offers a practical, non-invasive estimate of arterial CO₂ (PaCO₂), particularly in stable, anesthetized patients [10]. Nunn and Hill showed that the arterial–end-tidal gradient remains stable during anesthesia in healthy individuals, supporting ETCO₂ as a continuous surrogate for PaCO₂ [10]. While arterial blood gas is the gold standard, it is invasive and unsuitable for continuous monitoring [11].

ETCO₂ is widely used in operating rooms for general anesthesia and intubation [10]. However, factors such as age, surgical type, cardiopulmonary disease, and altered pulmonary perfusion can affect the ETCO₂–PaCO₂ correlation. In serious respiratory illness, especially in infants, deviations often signal ventilation–perfusion mismatch and potential physiological compromise [12].

Neonates and infants have distinct respiratory physiology—immature control of breathing, inefficient respiratory muscles, lower lung volumes, and high metabolic rates. Their compliant chest walls and stiff lungs predispose to early airway closure and rapid oxygen desaturation. To maintain functional residual capacity (FRC), they use compensatory strategies such as auto-PEEP and prolonged inspiratory muscle activity [13].

Capnography can be mainstream—direct airway measurement with minimal dead space and high precision, ideal for intubated patients—or sidestream, which samples gas via tubing and is suited for non-intubated patients but is more sensitive to environmental factors [14]. The choice depends on clinical context.

Normal ETCO₂ values in spontaneously breathing children are 36–40 mmHg, with a general pediatric range of 35–45 mmHg [14]. In very low birth weight infants, low tidal volumes and reduced exhaled CO₂ can decrease signal fidelity, necessitating technical adjustments and heightened vigilance [15]. ETCO₂ accuracy is also influenced by dynamic clinical status, including rapid changes in ventilation–perfusion matching (for example, acute lung injury, bronchospasm, atelectasis), fluctuations in cardiac output (for example: shock, sepsis, or during cardiopulmonary resuscitation), and metabolic alterations that affect CO₂ production (for example, fever or hypothermia). Environmental and technical factors, such as high fresh gas flow, oxygen supplementation via open systems, mask or circuit leaks, airway secretions, and sensor dead space, may further distort ETCO₂ measurements, particularly in neonates and small children. Beyond ventilation monitoring, ETCO₂ provides indirect circulatory insights, aiding in the assessment of CPR effectiveness and overall circulatory status in critical care [16].

ETCO₂ in airway management

Endotracheal intubation carries risks such as cardiac arrest, aspiration, airway edema, bleeding, or tube

malposition into the right bronchus or esophagus [17, 18]. Among these, unrecognised esophageal intubation is particularly dangerous, leading to hypoxemia, brain injury, and death. Recent data suggest that its incidence remains high, yet prompt detection and correction can prevent adverse outcomes [19]. Accurate confirmation of correct endotracheal tube (ETT) placement is therefore essential. While several methods exist, continuous waveform capnography is regarded as the gold standard [20, 21].

The Project for Universal Management of Airways (PUMA) proposed specific criteria for confirming ETT placement via continuous waveform capnography,

including a clinically appropriate capnogram pattern, cyclic CO₂ variation with respiration, consistent amplitude rise over seven breaths, and a peak ≥ 7.5 mmHg above baseline [19]. Multiple studies have shown near-perfect sensitivity and specificity [18], and international guidelines recommend its routine use alongside clinical assessment [22]. Implementation has dramatically reduced tube misplacement rates [23, 24].

Despite its strengths, capnography is not infallible. False-positive readings may occur after ingestion of carbonated beverages, while false-negative readings can result from low-flow states (e.g., cardiac arrest, pulmonary embolism), severe airway obstruction, pulmonary edema, or contamination of the sensor by gastric contents or certain drugs (e.g., epinephrine) [22, 25].

Alternative methods for ETT placement confirmation include clinical examination, video laryngoscopy, ultrasound, flexible bronchoscopy, and esophageal detector devices. Esophageal detector devices (EDDs) are simple adjuncts that rely on the anatomical and physiological differences between the trachea and esophagus. They typically consist of a self-inflating bulb or a large syringe attached to the proximal end of the endotracheal tube. When the tube is correctly positioned in the trachea, the rigid, cartilaginous airway remains patent and allows rapid aspiration of air, leading to immediate reinflation of the bulb or easy withdrawal of air into the syringe. In contrast, if the tube is mistakenly placed in the esophagus, the compliant esophageal walls collapse around the tube, impeding airflow and preventing bulb reinflation or syringe aspiration. However, EDD performance may be reduced in neonates and young infants due to the small, highly compliant airways, as well as in conditions such as obesity, pregnancy, severe bronchospasm, or airway obstruction. However, none match the diagnostic performance of continuous waveform capnography, which remains the cornerstone for rapid, reliable verification in both emergency and elective airway management (Table 1).

ETCO₂ as a prognostic marker in pediatric cardiac arrest

ETCO₂ has become an important noninvasive marker of cardiac output and pulmonary perfusion during pediatric CPR. Both adult and pediatric studies show that persistently low ETCO₂ suggests inadequate perfusion and poor resuscitation outcomes, while a sudden rise often signals return of spontaneous circulation (ROSC) [26, 27]. PALS and AHA guidelines recommend its use as a prognostic tool; after 20 min of high-quality CPR, ETCO₂ <10 mmHg is associated with a low likelihood of ROSC and may support termination decisions in a multimodal context [28, 29].

Table 1 ETCO₂ vs. other confirmation modalities for ETT placement

Method for ETT placement confirmation	Advantage	Limitations
ETCO ₂	The gold standard and most accurate method for ETT placement confirmation, with reported sensitivity and specificity near 100%.	Requires an additional method for confirmation, especially in low blood flow conditions.
Clinical assessment	A simple, non-invasive method including inspection of chest expansion and condensation in the ETT and auscultation of breath sounds. It can be used when exhaled CO ₂ cannot be detected.	Unreliable method to exclude unrecognised esophageal intubation.
Video laryngoscopy (VL)	It provides a direct approach for ET placement confirmation by visualization of the ET through the vocal cords. It is associated with a significant decrease in the incidence of esophageal intubation.	It requires the most expertise immediately available. A second independent practitioner is recommended.
Ultrasound	It is an accurate method to exclude esophageal intubation by the absence of the "double tract sign" and detection of "lung sliding"	Requires an expert and is time-consuming, especially if the equipment is not pre-prepared.
Flexible bronchoscopy	More reliable and simpler than VL. Visualize the tracheal rings, smooth muscles, and the tip of the tube above the carina.	Blood, secretions, and aspirated substances may obstruct the field of visualization. In addition, it is time-consuming, especially if the equipment is not pre-prepared.
Esophageal detector device (EDD)	A simple and cheap device that can differentiate between tracheal and esophageal placement with $>97\%$ accuracy.	Gives false-negative results in infants, parturients, and morbidly obese patients.

ETCO₂, end-tidal CO₂; ETT, endotracheal tube; VL, video laryngoscopy; EDD, Esophageal detector device

Although these thresholds derive largely from adult data, pediatric in-hospital CPR studies from the PIC-qCPR consortium report that end-tidal CO_2 values measured during active cardiopulmonary resuscitation, prior to ROSC, typically fall in the low-20 mmHg range. In this cohort, intra-CPR ETCO_2 values showed substantial overlap between ROSC and non-ROSC cases, with overall ROSC occurring in approximately 70% of events [30, 31]. Overlap in values means ETCO_2 should not be used in isolation. Continuous waveform capnography also provides real-time feedback on CPR quality, with declines prompting reassessment and rises suggesting improved perfusion [32, 33]. Overventilation can falsely lower ETCO_2 , by approximately 3–4 mmHg for every 10 excess breaths per minute, a phenomenon that applies during cardiopulmonary resuscitation as well as during spontaneous or controlled ventilation, underscoring the need for strict adherence to recommended ventilation rates when interpreting ETCO_2 during CPR [34, 35].

Capnography's utility extends to both high- and low-resource settings, with initiatives like *The Capnography Project* aiming to standardize use and reduce disparities [36]. Limitations include susceptibility to ventilation-perfusion mismatch, and equipment errors [37]. Used alongside other clinical measures, ETCO_2 serves as a dynamic biomarker linking physiology to action in pediatric resuscitation.

ETCO_2 in procedural sedation and respiratory monitoring

ETCO_2 monitoring is a valuable adjunct in pediatric procedural sedation, providing real-time ventilation assessment and enabling earlier detection of hypoventilation

than clinical signs or oxygen desaturation [38, 39]. This is crucial in children, where rapid physiological decline can occur with little warning. Pulse oximetry, though standard, may remain normal with supplemental oxygen despite inadequate ventilation [7, 40]. In contrast, capnography offers immediate feedback on respiratory rate, effort, and alveolar ventilation, facilitating prompt intervention (Fig. 1).

In pediatric ED sedation, multiple studies have confirmed capnography's superiority in detecting respiratory compromise over pulse oximetry or observation alone [38, 41, 42]. Lightdale et al. demonstrated that microstream capnography identified hypoventilation earlier than pulse oximetry, reducing hypoxemia risk [43], while Langan et al. found it detected all apnea episodes, over half of which were missed by standard monitors [38]. These findings highlight ETCO_2 's sensitivity in recognizing respiratory failure before clinical deterioration [44].

Incorporating capnography into sedation protocols has been linked to fewer adverse events, including hypoxemia, airway interventions, and procedural interruptions [45]. A meta-analysis by Askar et al. found it significantly reduced hypoxemia episodes during procedural sedation [46], reinforcing its safety benefits.

Barriers to routine use include limited provider familiarity with waveform interpretation, particularly among non-anesthesiologists [47, 48], cost concerns in resource-limited settings [47], and the absence of universal guidelines mandating its use. Practical challenges, such as securing nasal cannulas in young children, interference during facial procedures, and false alarms from

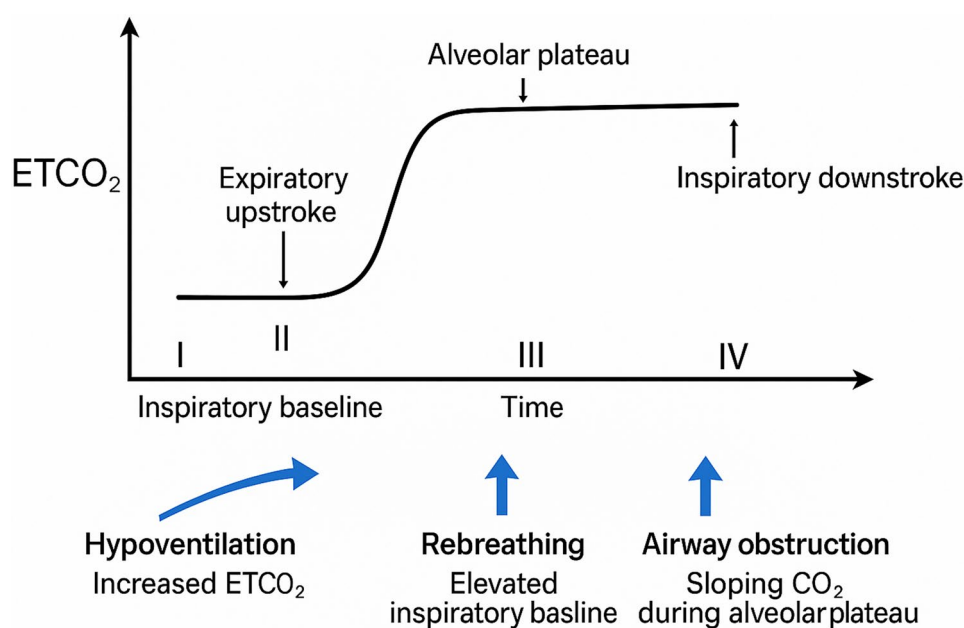
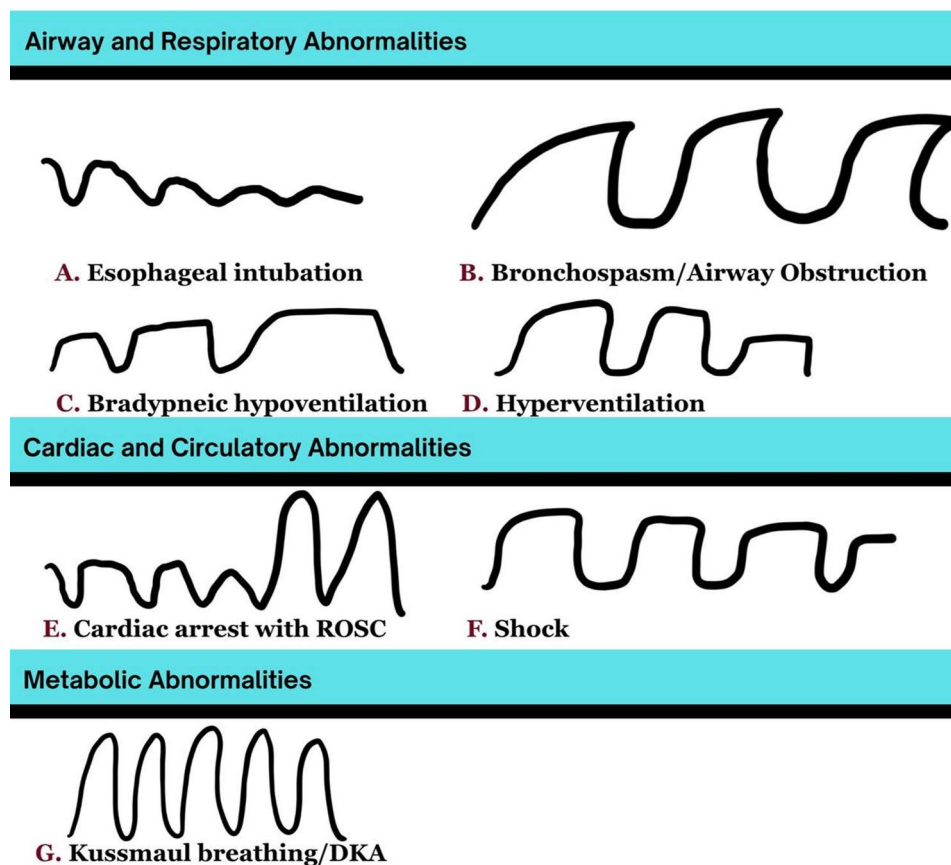


Fig. 1 - Capnogram phases and clinical interpretation

Table 2 Summary table of sedation-related adverse events detected by ETCO₂

Adverse Event	Detected Early by ETCO ₂ ?	Typical Detection Time Advantage	Clinical Significance
Hypoventilation	Yes	30–60 s before desaturation	Allows prompt intervention to prevent hypoxia
Apnea	Yes	Immediate detection (real-time)	Especially important in deep sedation or in young children prone to respiratory pauses
Airway obstruction	Yes	Early waveform change	Detects obstructive patterns (e.g., “shark-fin” waveform) before pulse oximetry oxygen saturation levels drop
Bradypnea	Yes	Immediate (breath-by-breath basis)	Indicates sedation depth is approaching unsafe level
Desaturation (SpO ₂ < 90%)	No	Detected late	Often occurs after ventilation is already critically impaired
Need for Airway Intervention	Indirectly via early signs	Preventable with early detection	Interventions like jaw thrust or bag-mask ventilation may be avoided or minimized
Unexpected deep sedation	Yes (via slow rate/apnea)	Early signs visible in waveform	Facilitates real-time titration of sedative agents

**Fig. 2** Waveforms of ETCO₂ across different conditions

movement or crying, can further hinder adoption [38, 43, 49, 50].

Overall, ETCO₂ monitoring during pediatric procedural sedation enhances early recognition of respiratory compromise and improves safety. Addressing training, cost, and technical hurdles is key to its consistent implementation in emergency care (Table 2). Figure 2 summarizes different waveforms seen in conditions in PED.

ETCO₂ in sepsis and shock

Sepsis is a maladaptive immune response to infection that results in organ dysfunction [51]. According to the Global Burden of Disease group, the incidence of sepsis in 2017 was 48.9 million cases, with 20.3 million cases in children younger than 5 and 4.9 million cases occurring in children and adolescents between the ages 5 and 19 [52]. With roughly half the cases occurring in children, it is clear that sepsis constitutes a greater burden in the pediatric population. Additionally, the pediatric

population takes the lead in terms of mortality rate with 2.9 million deaths related to sepsis in children younger than 5 and 454,000 deaths in those aged 5 to 19 out of a total of 11.0 million deaths [52].

Lactate levels in the blood and more specifically the duration of elevated lactate have been suggested to have a prognostic value in the management of sepsis [53, 54]. However, measuring lactate levels has its limitations. Measuring lactate in pediatric sepsis has disadvantages like the difficulty and risks of arterial sampling, inconsistent correlation between arterial vs. venous levels, and lactate's non-specificity. While useful, its predictive value is limited by inconsistent findings across studies, variable timing of draws, and the need for serial measurements [55].

Capnography is a non-invasive, real-time tool that can be used to measure end-tidal carbon dioxide (ETCO₂) which reflects arterial partial pressure of carbon dioxide (PCO₂) [56, 57]. This can be used to reflect perfusion in cases of shock, because it corresponds to the respiratory compensation in metabolic acidosis and it is expected that at lower perfusion, the lactate levels will be high and the ETCO₂ will be low [58]. Therefore, it can be used as a parameter of metabolic acidosis in various cases such as diabetic ketoacidosis and severe gastroenteritis [59, 60]. Its utility in sepsis has been explored in many published papers. Studies across pediatric and adult populations have demonstrated a significant inverse relationship between ETCO₂ and lactate levels suggesting its value in predicting sepsis and mortality in cases of suspected sepsis [58, 61]. This indicates that ETCO₂ can function as a non-invasive real-time test in the emergency department triage to rapidly assess the patients' risk of having sepsis or severe sepsis and possibly undergo blood lactate level testing to readily begin sepsis management. On the other hand, Guirgis et al. suggests that while it may be useful in the emergency department triage to predict sepsis, it doesn't correspond to the severity of sepsis or help decide treatment goals [62].

The use of capnography in the management of sepsis still has its limitations. ETCO₂ levels are affected by many different factors including ventilation, basal metabolic rate and cardiac output. In cases of sepsis with low perfusion, cardiac output is decreased which causes the pulmonary perfusion to drop. This increases alveolar dead space resulting in lower ETCO₂ independent of the changes in ventilation that are characteristic of the respiratory compensation associated with metabolic acidosis [28, 63]. Thus, it cannot always be a reliable indicator of lactate levels and the respiratory compensation in metabolic acidosis in a multisystemic disease like sepsis.

ETCO₂ in pediatric trauma and prehospital care

Trauma remains a leading cause of pediatric morbidity and mortality, and rapid recognition of respiratory and circulatory compromise is essential. Although most of the evidence for end-tidal carbon dioxide (ETCO₂) monitoring comes from anesthesia and resuscitation studies, its applications in pediatric trauma and prehospital care are increasingly recognized.

In children with traumatic brain injury (TBI), hypoventilation may go undetected when clinicians rely only on pulse oximetry, particularly if supplemental oxygen is administered. Capnography provides immediate and continuous information about ventilation, allowing earlier detection of rising PaCO₂ and the risk of secondary brain injury due to hypercapnia or intracranial hypertension [64]. Although ETCO₂ does not perfectly reflect arterial PaCO₂, especially in shock states, trending values is valuable when arterial blood gas analysis is delayed.

Equally important is its role in hemorrhagic shock, where ETCO₂ serves as a surrogate for pulmonary blood flow and cardiac output. Studies in trauma populations in adults show that ETCO₂ values below 30 mmHg are sensitive indicators of moderate-to-severe hemorrhagic shock, while values below 22 mmHg are highly specific for profound circulatory collapse [65]. Pediatric pilot data further suggest that lower ETCO₂ correlates inversely with serum lactate and predicts the need for massive transfusion [66]. In broader trauma series across adult patients, admission ETCO₂ has also been linked with blood transfusion requirements and mortality risk, underscoring its prognostic potential [67].

In the prehospital setting, waveform capnography is indispensable for airway verification. Unrecognized esophageal intubation remains a major source of morbidity, but continuous ETCO₂ monitoring has been shown to reduce misplacement from 23% to 0% in field studies [68]. During interfacility transport, ETCO₂ trends also provide dynamic information about both ventilation and perfusion, offering clinicians an early signal of deterioration when pulse oximetry and clinical examination may lag.

Taken together, these data highlight the pragmatic utility of ETCO₂ in pediatric trauma and transport. Its role is not limited to confirming endotracheal tube placement but extends to early detection of hypoventilation in TBI, perfusion monitoring in hemorrhagic shock, and continuous verification during prehospital and transport care. While pediatric-specific outcome studies are sparse, the physiologic rationale is compelling, and extrapolation from adult and mixed-age trauma literature strongly supports incorporating ETCO₂ into pediatric trauma protocols.

Limitations, challenges, and future directions

Despite its advantages, ETCO₂ monitoring presents a number of challenges related to pediatric emergency care. Technical problems, including mask leakage and equipment dead space, especially in infants and neonates, can lead to inaccurately low values [69, 70]. Sidestream device measurements could possibly be delayed or inaccurate in patients with low tidal volumes or high respiratory rates, particularly those with severe lung disease or ventilation-perfusion mismatch [70, 71].

In low-resource settings, implementation is made much more challenging by a lack of clear rules, inadequate training, and the high cost of monitors and disposables. In low- and middle-income countries (LMICs), capnography is still generally unavailable, which results in significant airway challenges and perioperative mortality [72, 73].

Recent efforts have focused on low-cost, portable solutions tailored for resource-limited environments, such as the Smile Train–Lifebox project, which combines technology with targeted education [74]. Looking ahead, wider adoption will require large multi-center pediatric studies, standardized training, and protocols to ensure safe and effective use. The integration of artificial intelligence may also enhance real-time interpretation and clinical decision-making [72, 73].

Conclusion

In conclusion, ETCO₂ monitoring is a crucial tool in pediatric emergency care, but its impact is limited by technical and systemic barriers. Overcoming these challenges through improved technology, standardized training, and broader access will be essential to ensure every child benefits from timely and accurate respiratory monitoring.

Author contributions

Consent to publish: All authors have reviewed the final draft and agree to the publication of the manuscript in its current form.

Funding

The authors did not receive support from any organization for the submitted work.

Data availability

No new data has been generated or analyzed.

Declarations

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publish

All authors have reviewed the final draft and agree to the publication of the manuscript in its current form.

Competing interests

The authors declare no competing interests.

Received: 5 September 2025 / Accepted: 20 December 2025

Published online: 08 January 2026

References

1. Chavez H, Garcia CT, Sakers C, Darko R, Hannan J. Epidemiology of the critically ill child in the resuscitation Bay. *Pediatr Emerg Care*. 2018;34(1):6–9.
2. Topjian AA, Raymond TT, Atkins D, et al. Part 4: pediatric basic and advanced life support: 2020 American heart association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation*. 2020;142(16). <https://doi.org/10.1161/CIR.0000000000000901>.
3. Coté CJ, Wilson S, American academy of pediatrics, american academy of pediatric dentistry. Guidelines for monitoring and management of pediatric patients before, during, and after sedation for diagnostic and therapeutic procedures. *Pediatrics*. 2019;143(6):e20191000. <https://doi.org/10.1542/peds.2019-1000>.
4. Chrimes N, Higgs A, Hagberg CA, et al. Preventing unrecognised oesophageal intubation: a consensus guideline from the project for universal management of airways and international airway societies. *Anaesthesia*. 2022;77(12):1395–415. <https://doi.org/10.1111/anae.15817>.
5. Berg KM, Bray JE, Ng KC, et al. 2023 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations: summary from the basic life support; advanced life support; pediatric life support; neonatal life support; education, implementation, and teams; and first aid task forces. *Circulation*. 2023;148(24). <https://doi.org/10.1161/CIR.0000000000001179>.
6. Langan ML, Chen L. Current utilization of continuous end-tidal carbon dioxide monitoring in pediatric emergency departments. *Pediatr Emerg Care*. 2008;24(4):211–3. <https://doi.org/10.1097/PEC.0b013e31816a8d31>.
7. Selby ST, Abramo T, Hobart-Porter N. An update on end-tidal CO₂ monitoring. *Pediatr Emerg Care*. 2018;34(12):888–92. <https://doi.org/10.1097/PEC.0000000000001682>.
8. Langan ML, Chen L, Marshall C, Santucci KA. Detection of hypoventilation by capnography and its association with hypoxia in children undergoing sedation with ketamine. *Pediatr Emerg Care*. 2011;27(5):394–7.
9. Kannikeswaran N, Chen X, Sethuraman U. Utility of endtidal carbon dioxide monitoring in detection of hypoxia during sedation for brain magnetic resonance imaging in children with developmental disabilities. *Pediatr Anesth*. 2011;21(12):1241–6.
10. Ickx B, Dolomie JO, Benalouch M, Melot C, Lingier P. (2015) Arterial to end-tidal carbon dioxide tension differences in infants and children. 2155–6148 6: 511. <https://doi.org/10.4172/2155-6148.1000511>
11. Wang W, Zhao Z, Tian X, et al. Noninvasive carbon dioxide monitoring in pediatric patients undergoing laparoscopic surgery: transcutaneous vs. end-tidal techniques. *BMC Pediatr*. 2023;23:20. <https://doi.org/10.1186/s12887-023-03836-2>.
12. Williams E, Dassios T, Greenough A. Assessment of sidestream end-tidal capnography in ventilated infants on the neonatal unit. *Pediatr Pulmonol*. 2020;55(6):1468–73. <https://doi.org/10.1002/ppul.24738>. Epub 2020 Mar 18. PMID: 32187888.
13. Saikia D, Mahanta B. Cardiovascular and respiratory physiology in children. *Indian J Anaesth* 63(9):p 690–697, September 2019. | https://doi.org/10.4103/ija.IJA_490_19
14. Damam S, Meshram RJ, Taksande A, Lohiya S, Khurana A, Patel A, Khandelwal R, Nath R, Javvaji CK, Kakkat S. Navigating pediatric capnography: A comprehensive review of scope and limitations. *Cureus*. 2024;16(1):e53289. <https://doi.org/10.7759/cureus.53289>. PMID: 38435961; PMCID: PMC10905056.
15. Coates BM, Chaize R, Goodman DM, et al. Performance of capnometry in non-intubated infants in the pediatric intensive care unit. *BMC Pediatr*. 2014;14:163. <https://doi.org/10.1186/1471-2431-14-163>.
16. Berg RA, Reeder RW, Meert KL, Yates AR, Berger JT, Newth CJ, Carcillo JA, McQuillen PS, Harrison RE, Moler FW, Pollack MM, Carpenter TC, Notterman DA, Holubkov R, Dean JM, Nadkarni VM, Sutton RM, Eunice Kennedy shriver national institute of child health and human development collaborative pediatric critical care research network (CPCCRN). Pediatric intensive care quality of Cardio-Pulmonary resuscitation (PICqCPR) investigators. End-tidal carbon dioxide during pediatric in-hospital cardiopulmonary resuscitation.

- Resuscitation. 2018;133:173–9. Epub 2018 Aug 15. PMID: 30118812; PMCID: PMC6258346.
17. Alenazi A, Alshibani A. Confirmatory methods for endotracheal tube placement in out-of-hospital settings: A systematic review of the literature. *Heliyon*. 2024;10(7):e28479.
 18. Sakles JC, Ross C, Kovacs G. Preventing unrecognized esophageal intubation in the emergency department. *J Am Coll Emerg Physicians Open*. 2023;4(3):e12951.
 19. Chrimes N, Higgs A, Hagberg CA, Baker PA, Cooper RM, Greif R, et al. Preventing unrecognized oesophageal intubation: a consensus guideline from the project for universal management of airways and international airway societies*. *Anaesthesia*. 2022;77(12):1395–415.
 20. Aminiahidashi H, Shafee S, Zamani Kiasari A, Sazgar M. Applications of End-Tidal carbon dioxide (ETCO₂) monitoring in emergency Department; a narrative review. *Emergency*. 2018;6(1):e5.
 21. Long B, Koyfman A, Vivirito MA. Capnography in the emergency department: A review of Uses, Waveforms, and limitations. *J Emerg Med*. 2017;53(6):829–42.
 22. Neumar RW, Otto CW, Link MS, Kronick SL, Shuster M, Callaway CW et al. Part 8: Adult advanced cardiovascular life support: 2010 American heart association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *circulation* [Internet]. 2010 Nov 2;122(18). Available from: <https://www.ahajournals.org/doi/https://doi.org/10.1161/CIRCULATIONAHA.110.970988.cited> 23 Jul 2025
 23. Wirtz DD, Ortiz C, Newman DH, Zhitomirsky I. Unrecognized misplacement of endotracheal tubes by ground prehospital providers. *Prehosp Emerg Care*. 2007;11(2):213–8.
 24. Silvestri S, Ralls GA, Krauss B, Thundiyil J, Rothrock SG, Senn A, et al. The effectiveness of Out-of-Hospital use of continuous End-Tidal carbon dioxide monitoring on the rate of unrecognized misplaced intubation within a regional emergency medical services system. *Ann Emerg Med*. 2005;45(5):497–503.
 25. Walsh BK, Crotwell DN, Restrepo RD. Capnography/Capnometry during mechanical ventilation: 2011. *Respir Care*. 2011;56(4):503–9.
 26. Erdem NB, Parlak İ, Kokkoz Ç, Erdem E, Ocak NY. Comparison of five conventional methods and capnography in the detection of tube placement in endotracheal intubation. *Demiroğlu Bilim Üniversitesi Florence Nightingale Tıp Derg*. 2018;4(4):167–72.
 27. Field JM, Hazinski MF, Sayre MR et al. Part 1: executive summary: 2010 American heart association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation*. 2010;122(18).
 28. McSwain SD, Hamel DS. End-tidal and arterial carbon dioxide measurements correlate across all levels of physiologic dead space. 2011.
 29. Berg RA, Reeder RW, Meert KL, et al. End-tidal carbon dioxide during pediatric in-hospital cardiopulmonary resuscitation. *Resuscitation*. 2018;133:173–9.
 30. Langhan ML, Emerson BL, Nett S, et al. End-Tidal carbon dioxide use for tracheal intubation: NEAR4KIDS registry. *Pediatr Crit Care Med*. 2018;19(2):98–105.
 31. Sutton RM, Reeder RW, Landis W, et al. Chest compression rates and pediatric in-hospital cardiac arrest survival outcomes. *Resuscitation*. 2018;130:159–66. <https://doi.org/10.1016/j.resuscitation.2018.07.015>.
 32. Williams E, Dassios T, Greenough A. Assessment of sidestream end-tidal capnography in ventilated infants. *Pediatr Pulmonol*. 2020;55(6):1468–73.
 33. Humphreys S, Schibler A, Von Ungern-Sternberg BS. Carbon dioxide monitoring in children—a narrative review. *Pediatr Anesth*. 2021;31(8):839–45.
 34. Wollner EA, Nourian MM, Bertille KK, et al. Capnography. *An Essent Monit Everywhere Anesth Analg*. 2023;137(5):934–42.
 35. Evans FM, Turc R, Echeto-Cerrato MA, et al. Capnography Project Anesth Analg. 2023;137(5):922–8.
 36. Damam S, Meshram RJ, Taksande A, et al. Navigating pediatric capnography: a comprehensive review. *Cureus*. 2024;16(1):e53289.
 37. Wang W, Zhao Z, Tian X, et al. Noninvasive carbon dioxide monitoring in pediatric laparoscopic surgery. *BMC Pediatr*. 2023;23:20.
 38. Ickx B, Dolomieu JO, Benalouch M, et al. Arterial to end-tidal carbon dioxide tension differences in infants and children. *J Anesth Clin Res*. 2015;6:511.
 39. Langhan ML, Shabanova V, Li FY, Bernstein SL, Shapiro ED. A randomized controlled trial of capnography during sedation in a pediatric emergency setting. *Am J Emerg Med*. 2015;33(1):25–30. <https://doi.org/10.1016/j.ajem.2014.09.050>.
 40. Nitzan M, Romem A, Koppel R. Pulse oximetry: fundamentals and technology update. *Med Devices (Auckl)*. 2014;7:231–9. <https://doi.org/10.2147/MDER.S47319>. Published 2014 Jul 8.
 41. Cummings JJ, Polin RA, COMMITTEE ON FETUS AND NEWBORN. Oxygen targeting in extremely low birth weight infants. *Pediatrics*. 2016;138(2):e20161576. <https://doi.org/10.1542/peds.2016-1576>.
 42. McQuillen KK, Steele DW. Capnography during sedation/analgesia in the pediatric emergency department. *Pediatr Emerg Care*. 2000;16(6):401–4. <http://doi.org/10.1097/00006565-200012000-00005>.
 43. Català Altarriba L, Yeh Hsi S, Ravit AM, Brió Sanagustín S, González-Rioja X. Non-invasive capnography versus pulse oximetry for early detection of respiratory depression during pediatric procedural sedation: a prospective observational study. *Children (Basel)*. 2025;12(7):938. <https://doi.org/10.3390/children12070938>. Published 16 Jul 2025.
 44. 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):e1170–8. <http://doi.org/10.1542/peds.2005-1709>.
 45. 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. <https://doi.org/10.1197/j.aem.2005.12.017>.
 46. Corbett G, Pugh P, Herre J, et al. Service evaluation of the impact of capnography on the safety of procedural sedation. *Front Med (Lausanne)*. 2022;9:867536. <https://doi.org/10.3389/fmed.2022.867536>. Published 2022 May 6.
 47. Askar H, Misch J, Chen Z, Chadha S, Wang HL. Capnography monitoring in procedural intravenous sedation: a systematic review and meta-analysis. *Clin Oral Investig*. 2020;24(11):3761–70. <https://doi.org/10.1007/s00784-020-03395-1>.
 48. Iyer NS, Koziel JR, Langhan ML. A qualitative evaluation of capnography use in paediatric sedation: perceptions, practice and barriers. *J Clin Nurs*. 2015;24(15–16):2231–8. <https://doi.org/10.1111/jocn.12848>.
 49. Shavit I, Leder M, Cohen DM. Sedation provider practice variation: a survey analysis of pediatric emergency subspecialists and fellows. *Pediatr Emerg Care*. 2010;26(10):742–7. <https://doi.org/10.1097/PEC.0b013e3181f70e4e>.
 50. Friesen RH, Alswang M. End-tidal PCO₂ monitoring via nasal cannulae in pediatric patients: accuracy and sources of error. *J Clin Monit*. 1996;12(2):155–9. <https://doi.org/10.1007/BF02078136>.
 51. Singer M, Deutschman CS, Seymour CW, Shankar-Hari M, Annane D, Bauer M, et al. The third international consensus definitions for sepsis and septic shock (Sepsis-3). *JAMA*. 2016;315(8):801–10.
 52. Rudd KE, Johnson SC, Agesa KM, Shackelford KA, Tsoi D, Kievlan DR, et al. Global, regional, and National sepsis incidence and mortality, 1990–2017: analysis for the global burden of disease study. *Lancet*. 2020;395(10219):200–11.
 53. Bakker J, Gris P, Coffernils M, Kahn RJ, Vincent JL. Serial blood lactate levels can predict the development of multiple organ failure following septic shock. *Am J Surg*. 1996;171(2):221–6.
 54. Gorgis N, Asselin JM, Fontana C, Heidersbach RS, Flori HR, Ward SL. Evaluation of the association of early elevated lactate with outcomes in children with severe sepsis or septic shock. *Pediatr Emerg Care*. 2019;35(10):661–5.
 55. Abdelaziz TA, Karam NA, Ismail WI, Askary NMA, Baz EG. Lactate dynamics in paediatric patients with severe sepsis: insights from a prospective cohort study. *BMC Pediatr*. 2024;24:345. <https://doi.org/10.1186/s12887-024-04809-9>.
 56. Barten CW, Wang ESJ. Correlation of end-tidal CO₂ measurements to arterial Paco₂ in nonintubated patients. *Ann Emerg Med*. 1994;23(3):560–3.
 57. Yosefy C. End tidal carbon dioxide as a predictor of the arterial PCO₂ in the emergency department setting. *Emerg Med J*. 2004 Sept 1;21(5):557–9.
 58. Cully M, Treut M, Thompson AD, DePiero AD. Exhaled end-tidal carbon dioxide as a predictor of lactate and pediatric sepsis. *Am J Emerg Med*. 2020;38(12):2620–4.
 59. Gilhotra Y, Porter P. Predicting diabetic ketoacidosis in children by measuring end-tidal CO₂ via non-invasive nasal capnography. *J Paediatr Child Health*. 2007;43(10):677–80.
 60. Nagler J, Wright RO, Krauss B. End-tidal carbon dioxide as a measure of acidosis among children with gastroenteritis. *Pediatrics*. 2006 June;118(1):260–7.
 61. Hunter CL, Silvestri S, Dean M, Falk JL, Papa L. End-tidal carbon dioxide is associated with mortality and lactate in patients with suspected sepsis. *Am J Emerg Med*. 2013;31(1):64–71.
 62. Guirgis FW, Williams DJ, Kalynych CJ, Hardy ME, Jones AE, Dodani S, et al. End-tidal carbon dioxide as a goal of early sepsis therapy. *Am J Emerg Med*. 2014;32(11):1351–6.

63. Andrews FJ. Critical care in the emergency department: monitoring the critically ill patient. *Emerg Med J* 2006 July 1;23(7):561–4.
64. Price J, Sandbach DD, Ercole A, Wilson A, Barnard EBG. End-tidal and arterial carbon dioxide gradient in serious traumatic brain injury after prehospital emergency anaesthesia: a retrospective observational study. *Emerg Med J*. 2020;37(11):674–9. <https://doi.org/10.1136/emermed-2019-209077>.
65. Örmeci GÖ, Yiğit Ö, Eray O. Utility of end tidal carbon dioxide to predict hemorrhagic shock in multiple trauma patients. *Turk J Med Sci*. 2021;52:206–15. <https://doi.org/10.3906/sag-2103-206>.
66. Safari E, Torabi M. Relationship between end-tidal co2 (Etco2) and lactate and their role in predicting hospital mortality in critically ill trauma patients; a cohort study. *Bull Emerg Trauma*. 2020;8(2):83–8. <https://doi.org/10.30476/BEAT.2020.46447>.
67. Wilson BR, Bruno J, Duckwitz M, Akers N, Jeanmonod D, Jeanmonod R. Prehospital end-tidal CO2 as an early marker for transfusion requirement in trauma patients. *Am J Emerg Med*. 2021;45:254–7. <https://doi.org/10.1016/j.ajem.2020.08.056>.
68. Silvestri S, Ralls GA, Krauss B, et al. The effectiveness of out-of-hospital use of continuous end-tidal carbon dioxide monitoring on the rate of unrecognized misplaced intubation within a regional emergency medical services system. *Ann Emerg Med*. 2005;45(5):497–503. <https://doi.org/10.1016/j.annemergmed.2004.09.014>.
69. Schmalisch G. Current methodological and technical limitations of time and volumetric capnography in newborns. *Biomed Eng OnLine*. 2016;15(1):104.
70. Humphreys S, Schibler A, Von Ungern-Sternberg BS. Carbon dioxide monitoring in children—A narrative review of physiology, value, and pitfalls in clinical practice. *Pediatr Anesth*. 2021;31(8):839–45.
71. Williams E, Dassios T, Greenough A. Carbon dioxide monitoring in the newborn infant. *Pediatr Pulmonol*. 2021;56(10):3148–56.
72. Wollner E, Nourian MM, Booth W, Conover S, Law T, Lilaonitkul M, et al. Impact of capnography on patient safety in high- and low-income settings: a scoping review. *Br J Anaesth*. 2020;125(1):e88–103.
73. Wollner EA, Nourian MM, Bertille KK, Wake PB, Lipnick MS, Whitaker DK. Capnography—An essential Monitor, everywhere: A narrative review. *Anesth Analg*. 2023;137(5):934–42.
74. Evans FM, Turc R, Echeto-Cerrato MA, Gathuya ZN, Enright A. Capnography Project *Anesth Analg*. 2023;137(5):922–8.

Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.