Received: 30 August 2023 | Revised: 15 March 2024 | Accepted: 25 March 2024

DOI: 10.1002/emp2.13170

JACEP OPEN
JOURNAL OF THE AMERICAN COLLEGE OF EMERGENCY PHYSICIANS OPEN
A GLOBAL JOURNAL OF EMERGENCY MEDICINE
WILEY

ORIGINAL ARTICLE

Pediatrics

Bias between capnometry and venous carbon dioxide during initial assessment of pediatric emergency department patients: A video-based study

Michael Stratton MD, MS[1,2] | **Kevin Overmann MD, MS**[1,2] | **Yin Zhang MS**[3] | **Richard Ruddy MD**[1,2]

[1]Division of Emergency Medicine, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, USA

[2]Department of Pediatrics, University of Cincinnati College of Medicine, Cincinnati, Ohio, USA

[3]Division of Biostatistics and Epidemiology, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, USA

Correspondence
Michael Stratton, 3333 Burnet Ave MLC 12000, Cincinnati, OH 45229, USA.
Email: Michael.Stratton@cchmc.org

Prior presentation: Presented as a Platform at Pediatric Academic Society 2022.

Abstract

Objective: The bias of capnometry ($ETCO_2$) and venous carbon dioxide ($vpCO_2$) among pediatric emergency department (PED) patients triaged to critical care areas is unknown. We aimed to explore correlations and bias between $ETCO_2$ and $vpCO_2$ÿand identify predictors of bias.

Methods: This was an observational, video-based, retrospective study comparing $ETCO_2$ and $vpCO_2$. Pediatric patients with simultaneous $ETCO_2$ and $vpCO_2$ data were included. Our primary aim utilized linear regressions to determine correlations and Bland–Altman analysis to assess bias. Our secondary aim utilized multiple regression to identify clinical covariates contributing to bias. Covariates included age, respiratory rate, heart rate, mean arterial blood pressure, capnometry interface, PED diagnosis, and PED disposition.

Results: A total of 200 PED patients with $ETCO_2$ and $vpCO_2$ data were included. The median (interquartile range [IQR]) $ETCO_2$, $vpCO_2$, and ΔCO_2 in mmHg were 38 (32, 46), 49 (41, 61), and 11 (4, 20), respectively. $ETCO_2$ ($r = 0.76$) and ΔCO_2 ($r = 0.71$) were highly correlated with $vpCO_2$. The mean bias between $ETCO_2$ and $vpCO_2$ was −14.1 mmHg (95% confidence interval [CI], −41.9 −13.7). The bias between $ETCO_2$ and $vpCO_2$ increased at higher values of each measure. $ETCO_2$ sampling interface was the only independent predictor of $vpCO_2$ in our multivariate analysis. Patients requiring bag-valve mask (BVM) ventilation had the highest median bias between $ETCO_2$ and $vpCO_2$ (29 mmHg, IQR 15, 37).

Conclusion: $ETCO_2$ and $vpCO_2$ were highly correlated. However, bias increased at higher levels of both $ETCO_2$ and $vpCO_2$. Among PED patients, $ETCO_2$'s ability to approximate $vpCO_2$ diminishes with worsening hypercarbic respiratory failure.

KEYWORDS
capnometry, pediatrics

Supervising Editor: Sing-Yi Feng, MD

1 | INTRODUCTION

1.1 | Background

Derangements in venous carbon dioxide ($vpCO_2$) are common and potentially life-threatening among severely ill and injured children. End-tidal capnometry ($ETCO_2$) quantifies exhaled carbon dioxide (CO_2) continuously and non-invasively. In healthy spontaneously breathing children, $ETCO_2$ should approximate normal venous carbon dioxide levels of 35–45 mmHg of CO_2.[1] Ward et al. provide a framework of three variables that affect bias between $ETCO_2$ and serum CO_2: (1) ventilation-perfusion abnormalities, (2) respiratory patterns that inhibit complete alveolar emptying, and (3) poor sampling.[2] In acute illness in pediatric emergency department (PED) patients, all three factors may be present and influence the accuracy of $ETCO_2$. $ETCO_2$ has been shown to have clinical utility confirming endotracheal placement; assessing respirations during sedations, seizures, bronchiolitis, and asthma; detecting metabolic disturbances (diabetic ketoacidosis, sepsis, trauma, and dehydration); as well as detecting cardiac output in cardiac arrest.[3–34] However, there is a gap in knowledge regarding the utility of $ETCO_2$ as a proxy for $vpCO_2$ during initial assessment of undifferentiated pediatric patients presenting to the emergency department (ED) with signs of critical illness.

1.2 | Importance

No study has utilized video recordings of real-world $ETCO_2$ data at the time of initial venous blood gas sampling among patients presenting to the PED. Video review uniquely allows the detailed study of PED resuscitations and supports accurate data collection of visible time-sensitive variables. We believe that a detailed video analysis of capnometry measurements during initial assessment of patients triaged to the PED critical care area will provide insight into the real time bias of $ETCO_2$ from $vpCO_2$ during initial assessment of critically ill children.

1.3 | Goals of this investigation

We aimed to utilize video recordings of $ETCO_2$ as viewed by the bedside clinician during the initial assessment of pediatric patients triaged to the PED critical care area. Our primary aim was to determine the correlation and bias between venous carbon dioxide ($vpCO_2$) with simultaneous $ETCO_2$ among a real-world PED patient during their initial evaluation in the PED resuscitation area. Our secondary aim was identifying clinical predictors of bias between $ETCO_2$ and $vpCO_2$.

The Bottom Line

In critical care pediatrics, the practitioner is increasingly dependent on data to make accurate clinical decisions regarding care. This study shows that capnometry can be used as a routine adjuvant alongside pulse oximetry unless the patient is in hypercarbic respiratory failure, most likely due to poor ventilation. More studies using capnometry in pediatric critically ill patients will be needed to further define its use.

2 | METHODS

2.1 | Study design and setting

This was a retrospective, video-based, observational study of pediatric patients undergoing initial evaluation and resuscitation in the critical care area of a PED. This study was determined to be exempt by our local institutional review board. The study site was a large urban tertiary free standing Children's Hospital. It is the major regional provider of emergency care to children and a level 1 pediatric trauma center, with approximately 62,000 annual encounters. A total of 4000 patients per year are evaluated in the critical care area. Each of the critical care bays is equipped with an audio-video recording system. There are three to four feeds for each resuscitation bay, one of which is the patient monitor. Capnometry data are included on the monitor, when used for the patient. Recordings are reviewed regularly for peer review and quality assurance activities, with strict policies for storage, review, and permanent deletion developed with medical center's legal counsel. Recordings occur continuously in all resuscitation bays and are available for review using a proprietary software program (Livecapture, B-Line Medical). The data collected from these recordings reflect real-world clinical data as experienced by the PED clinician during critical care. For this study, vpCO2 and $ETCO_2$ were obtained as part of the patients care at the discretion of the treating clinician.

2.2 | Selection of participants

Patients ≤18 years of age were identified for inclusion from the complete ED registry of patients who received care in the critical care area.[35] Only clinical encounters from the critical care area with $vpCO_2$ assessed were reviewed for potential inclusion. Patients with $ETCO_2$ measurements within 5 min of venous blood gas that could be directly observed on video were included. Patients without both measures or those in cardiac arrest were excluded. Demographic information as

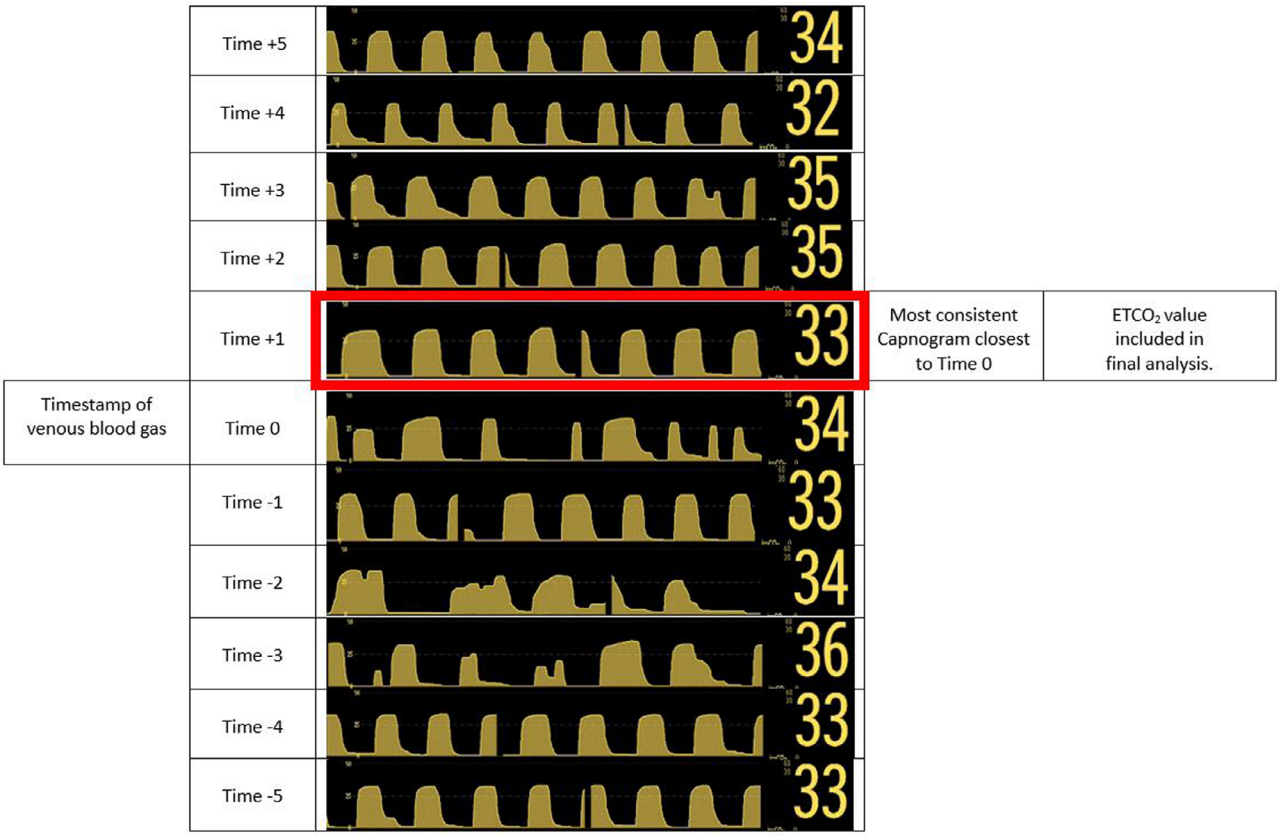

FIGURE 1 Example of sampled capnogram tracings and selection of $ETCO_2$ value included in final analysis. Time of venous blood gas sample, established as time zero (T_0). Capnogram tracings and capnometry values starting at T_0 were serially captured every minute for 5 min prior to T_0 and 5 min after T_0. From these 11 time points, the most stable capnogram waveform that was closest in time to T_0 was included in final analysis. Consistency of waveforms was prioritized rather than their morphologic approximation of a normal waveform. In this example, Time = +1(T_1) was included in the final analysis for the most consistent capnogram closest to Time = 0.

well as results of venous blood gas assessment were exported from the electronic medical record (EPIC, Madison Wisconsin).

2.3 | Measurements

2.3.1 | Capnometry and venous blood gas

The clinical monitoring system used for capnometry assessment in the critical care area was the IntelliVue X2 by Phillips. Capnometry readings were obtained via video recordings of Phillips microstream, a side stream capnography system. Capnometry can be measured by nasal, tracheostomy, bag-valve mask (BVM), or endotracheal tube (ETT) interfaces. $vpCO_2$ values were obtained via I-STAT (Abbott Point of Care Inc.), a point-of-care blood analyzer. After the blood sample was placed in the I-STAT analyzer, blood gas analysis results were generally available within 2 min.

2.3.2 | Capnogram classification

The venous blood gas sample result time, as recorded in our electronic health record, was identified and established as time zero (T_0) for our study. To determine which capnometry value was included in the final analysis, we serially captured the capnogram tracing and capnometry values starting at T_0 and then every minute for 5 min prior to T_0 and 5 min after T_0. From these 11 time points, the most stable capnogram waveform that was closest in time to T_0 was included in final analysis (Figure 1). We categorized capnogram waveforms into categories of stability based upon the waveforms directly preceding the leading edge of the capnogram tracing. In instances where there were more than five waveforms displayed on the capnogram, we visually inspected the capnogram and categorized the five preceding waveforms as "stable" (four to five waveforms of similar morphology), "intermediate" (two to three similar waveforms), or "unstable" (zero to one waveforms of similar morphology). We prioritized the consistency of waveforms (rather than their morphologic approximation of a normal waveform) to make these characterizations.[14]

2.4 | Clinical outcomes

Our primary predictor was $ETCO_2$ value, and our primary outcomes were $vpCO_2$ and the difference between $pvCO_2$ and $ETCO_2$ (ΔCO_2). Secondary outcomes were covariates associated with bias between $ETCO_2$ and $vpCO_2$. Covariates included age, respiratory rate, heart

rate, mean arterial blood pressure, capnometry interface, PED diagnosis, and PED disposition.

2.5 | Data analysis

2.5.1 | Data storage and statistical software

Data from video review and the electronic health record were stored, organized, and merged in REDCAP and R-studio.[36,37] Statistical testing was conducted using SAS.

2.5.2 | Statistical analysis

Descriptive statistics were used to describe a study sample. Linear regressions were performed, and Pearson correlation coefficients were calculated to determine correlation between continuous variables ($ETCO_2$, $vpCO_2$, and ΔCO_2). Multiple regression with backwards stepwise selection was performed to identify clinical covariates contributing to bias of $ETCO_2$ and $vpCO_2$. Covariates were selected a priori based upon presumed ability to influence $ETCO_2$ values and ability to reliably obtain covariates from video and electronic health record review of clinical encounters. Covariates included age, respiratory rate, heart rate, mean arterial blood pressure, capnometry interface, PED diagnosis, and PED disposition. Only significant covariates (p-value < 0.05) were included in the final model. A Bland–Altman plot was created to display the level of agreement (95% LOA) between $ETCO_2$ and $vpCO_2$.

2.5.3 | Missing data

To account for missing vital sign data for the covariates included in our multiple regression, we systematically replaced all the missing data by reviewing the images of the clinical monitor displaying the capnogram and capnometry data. If a vital sign was missing, the missing vital sign from the image of the clinical monitor that was closest in time to the missing value was included in final analysis. All missing vital sign data were able to be replaced with vital sign data from within 5 min of the time the venous blood gas resulted.

2.5.4 | Diagnostic categories

ICD-10 encounter diagnoses codes associated with the patient's presentation were grouped using the Pediatric Emergency Care Applied Research Network (PECARN) ICD-Based Diagnosis Grouping system (https://pecarn.org/tools/).[38] The PECARN Major Group Descriptions were utilized and encounters were classified into the following diagnostic categories: (1) neurologic disease; (2) trauma; (3) respiratory disease; (4) endocrine, metabolic, and nutrition. A fifth group called "Sepsis, Shock & Hypovolemia" was created to categorize ICD-10 codes that matched this clinical presentation. When ICD-10 codes were not associated with a Major Group Description or there were less than 15 instances of a given Major Group Description, ICD-10 description and chart review were utilized to categorize subjects into one of the above five categories. Upper airway and ear, nose, and throat presentations were included in respiratory disease. Toxic ingestions and psychiatric presentations were included in neurologic disease.

TABLE 1 Patient demographics, frequencies of capnometry interface observed and diagnostic categories.

Characteristic	N = 200
Age (years)	4.0 (1.0, 13.0[a])
Sex	
Female	90 (45%)
Male	110 (55%)
Capnometry Interface	
Nasal	151 (76%)
Bag-valve mask	38 (19%)
Endotracheal tube	4 (2.0%)
Tracheostomy	7 (3.5%)
Diagnostic categories	
Neurologic diseases	126 (63%)
Respiratory diseases	23 (12%)
Trauma	22 (11%)
Sepsis, shock, and hypovolemia	19 (9.5%)
Endocrine, metabolic, and nutritional diseases	10 (5.0%)
Capnogram waveform morphology	
Consistent	147 (74%)
Intermediate	36 (18%)
Variable	17 (8.5%)

[a]Median (IQR); *n* (%).

TABLE 2 Description of $ETCO_2$, $vpCO_2$, and ΔCO_2 for entire study sample, reported in median (IQR) mmHg.

Characteristic	Median (IQR)
$ETCO_2$	38 (32, 46)
$vpCO_2$	49 (41, 61)
ΔCO_2	11 (4, 20)

3 | RESULTS

We reviewed 428 consecutive clinical encounters with $vpCO_2$ obtained in the PED critical care area between December 2020 and August 2021 to constitute 200 patients meeting the required paired values of $ETCO_2$ and $pvCO_2$ observed on video. Our sample was 55% males. The median (interquartile range [IQR]) age in years was 4.0 (1.0, 13.0). Nasal capnometry was the interface utilized in

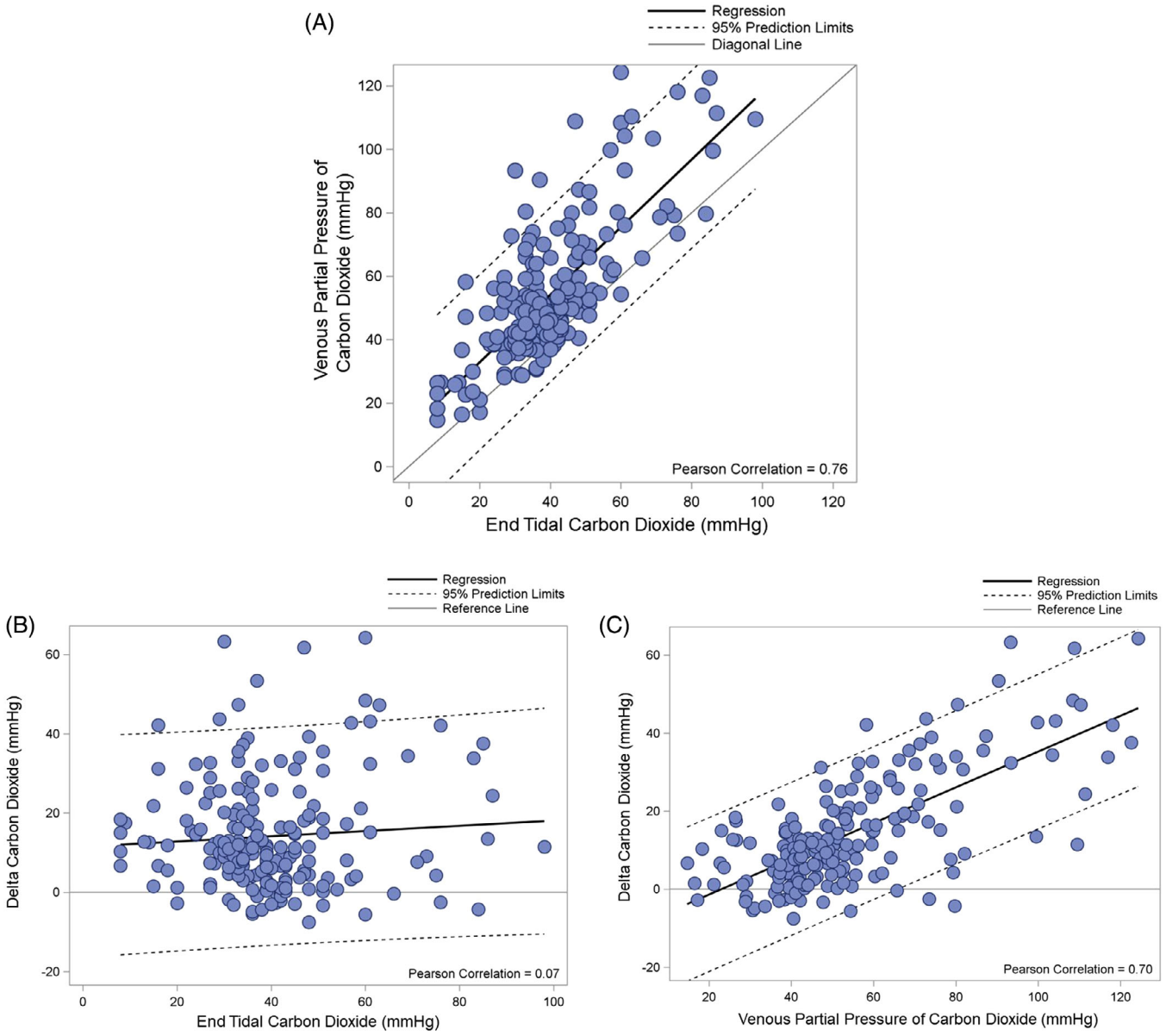

FIGURE 2 Univariate linear regressions: (A) correlation of capnometry ($ETCO_2$) value and venous partial pressure of carbon dioxide ($vpCO_2$), Pearson correlation of 0.75. (B) Correlation between $ETCO_2$ and ΔCO_2, Pearson correlation of 0.07. (C) Correlation between $vpCO_2$ and ΔCO_2, Pearson correlation of 0.7.

151 of 200 (75.5%) observations. Capnometry values from ETTs and tracheostomies were infrequently observed (5.5%). Capnometry was most frequently paired with a venous blood gas among patients presenting to the PED with concern for neurologic disease (63%). Capnometry values were associated with a stable capnography waveform in 74% of observations. (Table 1). In our sample, the median (IQR) values for our primary predictors and outcomes in mmHg were $ETCO_2$, 38 (32, 46), $vpCO_2$, 49 (41, 61), and ΔCO_2 11 (4, 20) (Table 2).

Capnometry as a predictor of $vpCO_2$ was plotted using simple linear regression. These were highly correlated with a Pearson Correlation coefficient of 0.76 with a slope of 1.07. Of note, there was greater variance between $ETCO_2$ and $vpCO_2$ at higher values and less variance at lower $ETCO_2$ and $vpCO_2$ values (Figure 2a). The $ETCO_2$ and ΔCO_2 are independent of each other with a Pearson correlation of 0.07 (Figure 2b). The $vpCO_2$ and ΔCO_2 are highly correlated with a Pearson correlation of 0.7 (Figure 2c). Bland–Altman analysis resulted in an estimated bias for the difference between $ETCO_2$ and $vpCO_2$ to be −14.1 mmHg with a 95% confidence interval of (−41.9 mmHg, 13.7 mmHg) (Figure 3). Visual inspections of the Bland–Altman plot display unequal bias between $ETCO_2$ and $vpCO_2$, with higher bias at higher mean values of $ETCO_2$ and $vpCO_2$.

To identify additional covariates associated with bias of $ETCO_2$ and $vpCO_2$, covariates (age, respiratory rate, heart rate, mean arterial blood pressure, capnometry interface, ED encounter diagnosis, and ED disposition) were modeled with a multiple regression with backwards stepwise elimination. Non-significant covariates were excluded

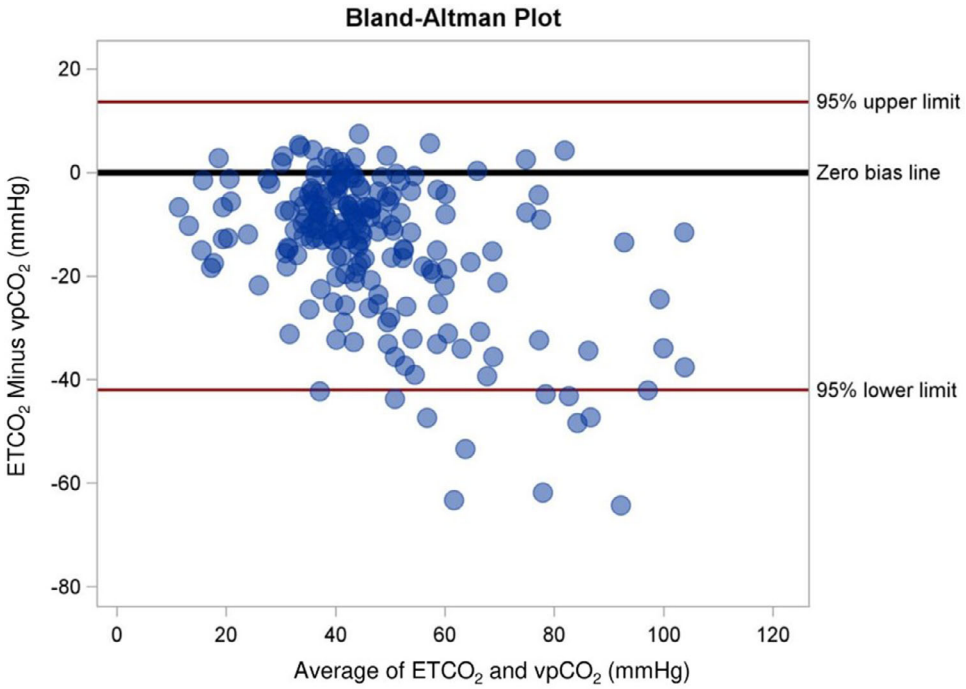

FIGURE 3 Bland–Altman plot of $ETCO_2$ compared with $vpCO_2$. The mean bias between these two values was −14.1 mmHg with a 95% confidence interval of −41.9 and 13.7 mmHg. The bias between $ETCO_2$ and $vpCO_2$ increases at higher values of each measure.

TABLE 3 Description of $ETCO_2$, $vpCO_2$, and ΔCO_2 stratified by capnometry interface, reported in median (IQR) mmHg.

Characteristic	Nasal, N = 151	Bag-Valve mask, N = 38	Endotracheal tube, N = 4	Tracheostomy, N = 7	*p*-value
$ETCO_2$	36 (30, 42)[a]	51 (38, 62)[a]	33 (27, 38)[a]	48 (34, 58)[a]	<0.001[b]
$vpCO_2$	46 (39, 53)[a]	76 (65, 93)[a]	41 (40, 47)[a]	60 (58, 83)[a]	<0.001[b]
ΔCO_2	9 (3, 15)[a]	29 (15, 37)[a]	16 (6, 24)[a]	20 (16, 32)[a]	<0.001[b]

[a]Median (IQR).
[b]Kruskal–Wallis rank sum test.

from the final model. Capnometry interface was the only significant covariate that was an independent predictor in our sample.

Median $ETCO_2$, $vpCO_2$, and ΔCO_2 were significantly different across capnometry interfaces. Of note, there were only 11 combined observations of $ETCO_2$ sampled by ETT and tracheostomy. BVM had higher median values of $ETCO_2$, $vpCO_2$, and ΔCO_2 (Table 3).

4 | LIMITATIONS

Our study has several limitations. The use of capnometry and obtaining of venous blood gas measurements during resuscitation in the PED was not set up in a standardized fashion. These data were available only retrospectively and were dependent on PED clinician practices. It should be noted that we were not able to determine a patient's tidal volume and include this in our analysis. We acknowledge that respiratory rate and tidal volume together fully assess a patient's ventilation. Our critical care area and video review of clinical encounters did not allow for feasible assessment of delivered tidal volume when assessing both $vpCO_2$ and $ETCO_2$. Our sample included a large proportion of neurologic-based clinical diagnoses more frequently than other important categories of illness or injury. We were only able to capture video recordings of patients in the critical care area and not standard PED care areas and therefore may not have included a full spectrum of patients in which capnometry was utilized. Additionally, our sample size was not large enough to draw generalizable conclusions across all $ETCO_2$ interfaces, specifically ETTs and tracheostomies, when compared to nasal and BVM values. Lastly, while blood gas measurements in PEDs are most commonly venous samples, findings from our study may be limited when compared to arterial measurements in other clinical settings.

5 | DISCUSSION

$ETCO_2$ and $vpCO_2$ were highly correlated in our sample of undifferentiated pediatric patients during initial evaluation and resuscitated in our PED. The high degree of correlation of $ETCO_2$ and $vpCO_2$ is consis-

tent with previous studies both inside and outside the PED.[16,17,26–34] However, strong correlation alone does not fully explain the clinical utility of these two measures of CO_2. Our results suggest that the bias between $ETCO_2$ and $vpCO_2$ is dependent upon a patient's degree of respiratory failure, with greater bias at higher CO_2 values, and worsening respiratory failure. The bias between $ETCO_2$ and $vpCO_2$ increased at higher CO_2 levels when assessed by simple linear regression. ΔCO_2 values increased at higher $vpCO_2$ values. The $ETCO_2$ interface with the highest ΔCO_2 was among those patients presenting with respiratory failure requiring immediate BVM respiratory support. Our Bland–Altman analysis displayed that at higher $ETCO_2$ and $vpCO_2$ values, the bias between these two values increases, and $ETCO_2$ often underestimates $vpCO_2$ especially at higher CO_2 values. Our results when taken together suggest that $ETCO_2$'s ability to approximate $vpCO_2$ diminishes among patients presenting to the PED with worse hypercarbic respiratory failure. The emergency clinician, when utilizing $ETCO_2$ during the initial assessment of pediatric patients, should interpret the absolute value of $ETCO_2$ with caution among patients who display signs of respiratory failure and those patients who display elevated $ETCO_2$ values during initial assessment.

In this retrospective video-based study comparing $ETCO_2$ to $vpCO_2$ during initial assessment and resuscitation in a single PED, we found that $ETCO_2$ is highly correlated with $vpCO_2$. However, there is greater bias between $vpCO_2$ and $ETCO_2$ among pediatric patients with hypercarbic respiratory failure. The worsening bias of $ETCO_2$ and $vpCO_2$ at higher $vpCO_2$ values is likely a direct result of inadequate ventilation, leading to alterations in the exhaled CO_2 that is detected by the $ETCO_2$ detector. Our findings support the emergency clinician using capnometry as a routine adjunctive tool during initial evaluation and resuscitation, but capnometry should be interpreted in the context of the patient's specific ventilatory status. Future studies of capnometry during initial evaluation and resuscitation of critically ill pediatric patients in the PED should focus upon $ETCO_2$ in patients with respiratory failure requiring ventilatory support.

AUTHOR CONTRIBUTIONS

Michael Stratton, Kevin Overmann, Richard Ruddy, and Yin Zhang conceived and designed the study. Michael Stratton performed data collection, and Michael Stratton and Kevin Overmann supervised data collection. Yin Zhang provided statistical advice and analyzed the data. Michael Stratton, Kevin Overmann, and Richard Ruddy drafted the manuscript, and all authors contributed substantially to its revision. Michael Stratton takes full responsibility for the paper as a whole.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

Michael Stratton MD, MS https://orcid.org/0000-0002-6834-1587

REFERENCES

1. Gravenstein JS, Jaffe MB, Gravenstein N, Paulus DA Capnography, second edition. Cambridge University Press. 2011.
2. Ward KR, Yealy DM. End-tidal carbon dioxide monitoring in emergency medicine, part 1: basic principles. *Acad Emerg Med*. 1998;5(6):628-636. doi: 10.1111/j.1553-2712.1998.tb02473.x
3. Guthrie BD, Adler MD, Powell EC. End-tidal carbon dioxide measurements in children with acute asthma. *Acad Emerg Med*. 2007;14(12):1135-1140. doi: 10.1197/j.aem.2007.08.007
4. Kunkov S, Pinedo V, Silver EJ, Crain EF. Predicting the need for hospitalization in acute childhood asthma using end-tidal capnography. *Pediatr Emerg Care*. 2005;21(9):574-577. doi: 10.1097/01.pec.0000177197.83655.d8
5. Evered L, Ducharme F, Davis GM, Pusic M. Can we assess asthma severity using expiratory capnography in a pediatric emergency department? *Cjem*. 2003;5(3):169-170. doi:10.1017/s1481803500006564
6. Vo AT, Liu DR, Schmidt AR, Festekjian A. Capillary blood gas in infants with bronchiolitis: can end-tidal capnography replace it? *Am J Emerg Med*. 2021;45:144-148. doi:10.1016/j.ajem.2021.04.056
7. Jacob R, Bentur L, Brik R, Shavit I, Hakim F. Is capnometry helpful in children with bronchiolitis? *Respir Med*. 2016;114:67-71. doi:10.1016/j.rmed.2016.02.007
8. Abramo TJ, Wiebe RA, Scott SM, Primm PA, McIntyre D, Mydler T. Noninvasive capnometry in a pediatric population with respiratory emergencies. *Pediatr Emerg Care*. 1996;12(4):252-254. doi:10.1097/00006565-199608000-00004
9. Abramo TJ, Wiebe RA, Scott S, Goto CS, McIntire DD. Noninvasive capnometry monitoring for respiratory status during pediatric seizures. *Crit Care Med*. 1997;25(7):1242-1246. doi:10.1097/00003246-199707000-00029
10. Abramo TJ, Wiebe RA, Garcia E, Bracken A, Scott S. Noninvasive monitoring capnometry for continuous monitoring of metabolic status in pediatric diabetic ketoacidosis (DKA). *Critical Care*. 2001;5(1):P132-P132. doi:10.1186/cc1199
11. Garcia E, Abramo TJ, Okada P, Guzman DD, Reisch JS, Wiebe RA. Capnometry for noninvasive continuous monitoring of metabolic status in pediatric diabetic ketoacidosis. *Crit Care Med*. 2003;31(10):2539-2543. doi:10.1097/01.CCM.0000090008.79790.A7
12. Abramo TJ, Cowan MR, Scott SM, Primm PA, Wiebe RA, Signs M. Comparison of pediatric end-tidal CO_2 measured with nasal/oral cannula circuit and capillary PCO_2. *Am J Emerg Med*. 1995;13(1):30-33. doi:10.1016/0735-6757(95)90236-8
13. Anderson JL, Junkins E, Pribble C, Guenther E. Capnography and depth of sedation during propofol sedation in children. *Ann Emerg Med*. 2007;49(1):9-13. doi:10.1016/j.annemergmed.2006.06.011
14. 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
15. Nagler JMD, Krauss BMDE. Capnography: a valuable tool for airway management. *Emerg Med Clin North Am*. 2008;26(4):881-897. doi:10.1016/j.emc.2008.08.005
16. Taghizadieh A, Pouraghaei M, Moharamzadeh P, Ala A, Rahmani F, Basiri Sofiani K. Comparison of end-tidal carbon dioxide and arterial blood bicarbonate levels in patients with metabolic acidosis referred to emergency medicine. *J Cardiovasc Thorac Res*. 2016;8(3):98-101. doi:10.15171/jcvtr.2016.21
17. 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;38:2620-2624. doi:10.1016/j.ajem.2020.07.075
18. Freedman SB, Johnson DW, Nettel-Aguirre A, et al. Assessing dehydration employing end-tidal carbon dioxide in children with vomiting and diarrhea. *Pediatr Emerg Care*. 2018;34(8):564-569. doi:10.1097/pec.0000000000001177
19. Redant S, Angoulvant F, Honore PM, Attou R, Biarent D, Bels DD. Unknown use of end-tidal CO_2 in metabolic emergencies in pediatric patients. *J Transl Intern Med*. 2019;7(2):76-78. doi:10.2478/jtim-2019-0015

20. Yang HW, Jeon W, Min YG, Lee JS. Usefulness of end-tidal carbon dioxide as an indicator of dehydration in pediatric emergency departments: a retrospective observational study. *Medicine (Baltimore)*. 2017;96(35):e7881. doi:10.1097/md.0000000000007881
21. Nagler J, Wright RO, Krauss B. End-tidal carbon dioxide as a measure of acidosis among children with gastroenteritis. *Pediatrics*. 2006;118(1):260-267. doi:10.1542/peds.2005-2723
22. Taeb M, Levin AB, Spaeder MC, Schwartz JM. Comparison of pediatric cardiopulmonary resuscitation quality in classic cardiopulmonary resuscitation and extracorporeal cardiopulmonary resuscitation events using video review. *Pediatr Crit Care Med*. 2018;19(9):831-838. doi:10.1097/PCC.0000000000001644
23. Sullivan KJ, Kissoon N, Goodwin SR. End-tidal carbon dioxide monitoring in pediatric emergencies. *Pediatr Emerg Care*. 2005;21(5):327-332. doi:10.1097/01.pec.0000159064.24820.bd
24. Bhende MS, Karasic DG, Menegazzi JJ. Evaluation of an end-tidal CO_2 detector during cardiopulmonary resuscitation in a canine model for pediatric cardiac arrest. *Pediatr Emerg Care*. 1995;11(6):365-368. doi:10.1097/00006565-199512000-00008
25. Topjian AA, Caen AD, Wainwright MS, et al. Pediatric post–cardiac arrest care: a scientific statement from the American Heart Association. *Circulation*. 2019;140(6):e194-e233. doi:10.1161/CIR.0000000000000697
26. Lindström V, Svensen CH, Meissl P, Tureson B, Castrén M. End-tidal carbon dioxide monitoring during bag valve ventilation: the use of a new portable device. *Scand J Trauma Resusc Emerg Med*. 2010;18(1):49-49. doi:10.1186/1757-7241-18-49
27. Fujimoto S, Suzuki M, Sakamoto K, et al. Comparison of end-tidal, arterial, venous, and transcutaneous P(CO(2)). *Respir Care*. 2019;64(10):1208-1214. doi:10.4187/respcare.06094
28. Campion EM, Robinson CK, Brant N, et al. End-tidal carbon dioxide underestimates plasma carbon dioxide during emergent trauma laparotomy leading to hypoventilation and misguided resuscitation: a Western Trauma Association Multicenter Study. *J Trauma Acute Care Surg*. 2019;87(5):1119-1124. doi:10.1097/TA.0000000000002469
29. Yousuf T, Brinton T, Murtaza G, et al. Establishing a gradient between partial pressure of arterial carbon dioxide and end-tidal carbon dioxide in patients with acute respiratory distress syndrome. *J Investig Med*. 2017;65(2):338-341. doi:10.1136/jim-2016-000253
30. Singh BS, Gilbert U, Singh S, Govindaswami B. Sidestream microstream end tidal carbon dioxide measurements and blood gas correlations in neonatal intensive care unit. *Pediatr Pulmonol*. 2013;48(3):250-256. doi:10.1002/ppul.22593
31. Nik Ab Rahman NH, Mamat AF. The use of capnometry to predict arterial partial pressure of CO_2 in non-intubated breathless patients in the emergency department. *Int J Emerg Med*. 2010;3(4):315-320. doi:10.1007/s12245-010-0233-5
32. Delerme SMD, Freund Y, Renault RMD, et al. Concordance between capnography and capnia in adults admitted for acute dyspnea in an ED. *Am J Emerg Med*. 2010;28(6):711-714. doi:10.1016/j.ajem.2009.04.028
33. Moses JM, Alexander JL, Agus MS. The correlation and level of agreement between end-tidal and blood gas pCO_2 in children with respiratory distress: a retrospective analysis. *BMC Pediatr*. 2009;9:20. doi:10.1186/1471-2431-9-20
34. Jabre P, Jacob L, Auger H, et al. Capnography monitoring in nonintubated patients with respiratory distress. *Am J Emerg Med*. 2009;27(9):1056-1059. doi:10.1016/j.ajem.2008.08.017
35. Dean P, Edmunds K, Shah A, et al. Video laryngoscope screen visualization and tracheal intubation performance: a video-based study in a pediatric emergency department. *Ann Emerg Med*. 2022;79(4):323-332. doi:10.1016/j.annemergmed.2021.11.019
36. Harris PA, Taylor R, Minor BL, et al. The REDCap consortium: building an international community of software platform partners. *J Biomed Inform*. 2019;95:103208-103208. doi:10.1016/j.jbi.2019.103208
37. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. 2009;42(2):377-381. doi:10.1016/j.jbi.2008.08.010
38. Alessandrini EA, Alpern ER, Chamberlain JM, Shea JA, Gorelick MH. A new diagnosis grouping system for child emergency department visits. *Acad Emerg Med*. 2010;17(2):204-213. doi:10.1111/j.1553-2712.2009.00635.x

How to cite this article: Stratton M, Overmann K, Zhang Y, Ruddy R. Bias between capnometry and venous carbon dioxide during initial assessment of pediatric emergency department patients: A video-based study. *JACEP Open*. 2024;5:e13170. https://doi.org/10.1002/emp2.13170

AUTHOR BIOGRAPHY

Michael Stratton, MD, is an Assistant Professor in the Department of Pediatrics at University of Cincinnati College of Medicine in Cincinnati, Ohio.