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ORIGINAL RESEARCH

General Medicine

The utility of transcutaneous carbon dioxide measurements in the emergency department: A prospective cohort study

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Abstract

Background: Rapid identification of patients with occult injury and illness in the emergency department can be difficult. Transcutaneous carbon dioxide (TCO_2) and oxygen (TO_2) measurements may be non-invasive surrogate markers for the identification of such patients.

Objectives: To determine if TCO_2 or TO_2 are useful adjuncts for identifying severe illness and the correlation between TCO_2, lactate, and end tidal carbon dioxide ($ETCO_2$).

Methods: Prospective TCO_2 and TO_2 measurements at a tertiary level 1 trauma center were obtained using a transcutaneous sensor on 300 adult patients. Severe illness was defined as death, intensive care unit (ICU) admission, bilevel positive airway pressure, vasopressor use, or length of stay >2 days. TCO_2 and TO_2 were compared to illness severity using *t* tests and correlation coefficients.

Results: Mean TO_2 did not differ between severe illness (58.9, 95% CI 54.9–62.9) and non-severe illness (58.0, 95% CI 54.7–61.1). Mean TCO_2 was similar between severe (34.6, 95% CI 33–36.2) vs non-severe illness (35.9, 95% CI 34.7–37.1). TCO_2 was 28.7 (95% CI 24.0–33.4) for ICU vs. 35.9 (95% CI 34.9–36.9) for non-ICU patients. The mean TCO_2 in those with lactate > 2.0 was 29.8 (95% CI 25.8–33.8) compared with 35.7 (95% CI 34.9–36.9) for lactate < 2.0. TCO_2 was not correlated with $ETCO_2$ ($r = 0.32$, 95% CI 0.22–0.42).

Conclusion: TCO_2 could be a useful adjunct for identifying significant injury and illness and patient outcomes in an emergency department (ED) population. TO_2 did not predict severe illness. TCO_2 and $ETCO_2$ are only moderately correlated, indicating that they are not equivalent and may be useful under different circumstances.

KEYWORDS
critical care, emergency department, emergency medicine, end tidal carbon dioxide, prehospital care, transcutaneous carbon dioxide, transcutaneous oxygen

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1 | INTRODUCTION

1.1 | Background

Rapid identification of patients with occult injury and illness in the emergency department (ED) is sometimes difficult. The predictive value of lactate in identification and prognostication of illness severity previously has been well established.[1,2] More recently, studies have demonstrated the utility of end tidal carbon dioxide ($ETCO_2$) in predicting outcome severity in sepsis, cardiac arrest, diabetic ketoacidosis, and trauma.[3–6] Use of these and other surrogate markers may be of critical importance in early identification of illness severity in the ED setting. It also has the potential to be a useful guide to resuscitation. Innovative and accurate methods for early detection of these patients are important for improvement of ED processes.

1.2 | Importance

Arterial blood gas (ABG) and venous blood gas (VBG) measurements sometimes are used to assess acidosis, respiratory status, and tissue perfusion. However, these tests can be time consuming and invasive. In addition, delays in sample acquisition and laboratory turnaround time can limit clinical utility in critically ill patients. Transcutaneous carbon dioxide (TCO_2) and transcutaneous oxygen (TO_2) monitors are a relatively recent development. They measure the partial pressure of carbon dioxide ($PaCO_2$) and partial pressure of oxygen (PaO_2) similar to a VBG, but through the skin and at the capillary level. Measurements provide rapid real-time, non-invasive measures of perfusion and ventilation at the level of capillary perfusion.

Previous studies have demonstrated utility of transcutaneous sensors during sedation[7] and the monitoring of neonates[8] and critically ill patients.[9] Studies have also demonstrated a correlation between TO_2 and cardiac output.[10] However, a prospective study assessing TCO_2 and TO_2 in the ED on undifferentiated patients has not been conducted. TCO_2 and TO_2 may be non-invasive surrogate markers for the identification of patients with occult or serious illness or injury.

1.3 | Goals of this investigation

The primary goal of this study was to conduct an initial prospective assessment of TCO_2 and TO_2 as adjuncts for identifying the severity of injury and illness in an ED population. Specifically, the predictive value of TCO_2 and TCO_2 for specific disease processes were assessed. Secondary outcomes included evaluating the correlation between TCO_2 and $ETCO_2$, measured TO_2 versus pulse oximetry, TCO_2 and lactate level, initial TCO_2 versus steady state TCO_2, and central versus peripheral TCO_2 and TO_2 measurements.

The Bottom Line

In the identification and prognostication of critical illness, such as sepsis, cardiac arrest, diabetic ketoacidosis, and trauma, the utility of end tidal carbon dioxide ($ETCO_2$) is attracting attention. The authors prospectively investigated transcutaneous CO_2 measurements as an adjunct for assessing severity of illness in a series of 300 emergency department (ED) patients, finding notable correlations with illness severity. Transcutaneous CO_2 could be a useful adjunct for identifying the severely ill patients in the ED.

2 | MATERIALS AND METHODS

2.1 | Study design and setting

This prospective cohort study was approved by the institutional review board and conducted at the ED of Orlando Regional Medical Center, Orlando, Florida. This ED is a Level I trauma center and a major tertiary care referral center. The ED cares for approximately 156,000 combined adult and pediatric patients per year.

2.2 | Selection of participants

We included a convenience sample of adult (age > = 18 years) patients presenting to the ED during July and August. Patients who were actively undergoing cardiopulmonary resuscitation on arrival were excluded. The selection and enrollment of patients occurred in the higher acuity section of the ED to increase the likelihood of enrolling patients with severe illness.

2.3 | Interventions

Enrolled patients had 2 of SenTec's 510k-FDA cleared OxiVenT sensors (Figure 1) placed on arrival, with initial readings recorded and continuous measurements until steady state equilibration was obtained. The sensor reports transcutaneous measurements of PaO_2 and $PaCO_2$ (similar to VBG). One sensor was placed in a central location (head or chest) and one in a peripheral location (arm or leg). After hospital discharge, enrolled patients underwent systematic chart review of their hospital course. At enrollment, all patients had vital signs, pulse oximetry, and $ETCO_2$ measurements performed. If available, concurrently drawn ABG and lactate levels were also recorded.

FIGURE 1 SenTec's OxiVenT sensor. Description: SenTec's OxiVenT transcutaneous sensor that was placed on patient's head/torso and arm/leg

2.4 | Measurements

TCO_2 and TO_2 were measured both centrally and peripherally using the OxiVenT sensor (Figure 1) at arrival. Researchers manually collected sensor readings and vital signs. Central probes were placed on the head or torso and peripheral probes were place on the extremities. Readings were recorded at arrival and 15 minutes (steady state). The manufacturer recommends measurements be recorded 90–120 seconds after initial probe placement to allow for warmup and subsequent highest accuracy. Steady state measurements were taken at 15 minutes, several times longer than manufacturer recommendation, to ensure accurate readings. Four measurements separated by both location and time were taken to maximize the precision and reliability of results. Measurements were not shared with the clinical care team.

After hospital discharge, 2 researchers completed a systematic chart review of enrolled patient's hospital course. Data were extracted on demographics, outcomes, final diagnosis, length of stay (LOS), lactate, complete blood count, comprehensive metabolic panel, d-dimer, troponin, creatine kinase, urinalysis, blood cultures, ABG, quick sequential organ failure assessment score, shock index, imaging results, mode of arrival, prehospital treatment, and disposition. A third researcher reviewed the entire database and analyzed for completeness, consistency, and validity. In the very few cases of missing TCO_2 and TO_2 measurements (N = 5), the alternative time point (T = 0 or T = 15 minutes) was duplicated, provided there was consistency with T = 0 and T = 15 minute readings on the other body locations. In the case of incomplete data (N = 1), the patient data were removed from the study subset.

2.5 | Outcomes

The primary outcome was severe illness. Severe illness was defined as a composite poor outcome of death, endotracheal intubation, ICU admission, bilevel positive airway pressure (BiPAP) use, vasopressor use, or hospital LOS >2 days. Secondary outcomes included $ETCO_2$, pulse oximetry, lactate level, steady state TCO_2, and central versus TCO_2 and TO_2 measurements.

2.6 | Analysis

The number of study participants was determined based on initial power calculations, which were consistent with previous work at our institution with $ETCO_2$.[11] In this study, it was assumed that 10%–15% of patients would meet severe illness definition. We estimated that a total sample of 288 patients (36 with a severe illness and 252 without severe illness) would achieve 80% power to detect a difference of 4 mmHg between the 2 groups with a significance level of 0.05.

Unless otherwise specified, analysis was conducted using TCO_2 and TO_2 values measured at 15 minutes (steady state) on the patient's head or torso. Normal values of TCO_2 and TO_2 are comparable to VBG, with PO_2 varying from 30–70 mmHg and PCO_2 ranging from 35–50 mmHg. TCO_2 was compared between patients who had severe and non-severe illness using the 2 sample unequal variance *t* test. In addition, TCO_2 levels were compared between patients with individual markers of severe illness, including ICU admission, endotracheal intubation, vasopressor use, mortality, BiPAP use, and admission longer than 2 days. TCO_2 was also assessed for patients with a lactate greater than 2 mmol/L and those less than or equal to this level.

Similar to TCO_2, the TO_2 was compared between patients that had severe and non-severe illness using the 2-sample unequal variance *t* test in the entire population. TO_2 levels were also compared between those patients with individual markers of severe illness, as outlined previously, and those without.

The correlation between illness significance and each measure (TCO_2, TO_2, $ETCO_2$, lactate, probe location, and timing of data acquisition) was assessed using the Pearson correlation coefficient. The Pearson correlation was used as it reflects the statistical relationship between the 2 sets of continuous, linear, related datasets. Each of the aforementioned measures also had their correlation assessed to the other listed measures. Finally, we compared the subset of patients with a TCO_2 and $ETCO_2$ gap of $>$ 10 mmHg to those with a gap of $<$ 10 mmHg by age, diagnoses, anion gap, and length of stay.

3 | RESULTS

3.1 | Characteristics of study subjects

Enrollment was completed at 300 patients, including 1 erroneously duplicated and incomplete subject that was removed from statistical analysis. Table 1 reveals the characteristics of the study subjects.

4 | MAIN RESULTS

Overall, 207 (69.2%) patients were admitted to the hospital from the ED with 11 (3.7%) requiring ICU level of care and 6 (2.0%)

TABLE 1 Characteristics of study subjects. Total of n = 299 subjects

Characteristic	N (%)
Gender	
Male	151 (50.5)
Female	148 (49.5)
Age	
Mean, SD (range) years	56.7, 17.8 (18–93)
Race	
Asian	5 (1.7)
Black	93 (31.1)
Caucasian	124 (41.5)
Hispanic	2 (0.6)
Native American	0
Pacific Islander	0
Other	75 (25.1)
Mode of Arrival	
Ambulance	161 (53.8)
Walk-in	138 (46.2)
Disposition	
Admission	207 (69.2)
ICU	11 (3.7)
In-hospital mortality	6 (2.0)

experiencing in-hospital mortality. Of the 299 patients, 102 met the definition of severe illness, a composite poor outcome that included death, ICU admission, BiPAP use, vasopressor use, or LOS > 2 days.

4.1 | Comparison of mean TCO_2 and TO_2 with severe and non-severe illness

The mean TO_2 did not differ between severe illness (58.9 mmHg, 95% CI 54.9–62.9) vs. non-severe illness (58.0 mmHg, 95% CI 54.7–61.1). Mean TCO_2 was similar between severe illness (34.6 mmHg, 95% CI 33–36.2) vs. non-severe illness (35.9 mmHg, 95% CI 34.7–37.1).

4.2 | Comparison of mean TCO_2, $ETCO_2$, and TO_2 with clinical outcomes

The mean TCO_2 in specific outcomes is summarized in Figure 2. The TCO_2 was significantly lower for ICU admitted patients (28.7 mmHg, 95% CI 24.0–33.4) compared to non-ICU patients (35.7 mmHg, 95% CI 34.7–36.7). $ETCO_2$ was lower in the severe illness group (30.3 mmHg, 95% CI 28.9–31.7) than the non-severe illness group (33.3 mmHg, 95% CI 32.3–34.3). In addition, Table 3 demonstrates the TCO_2 results and $ETCO_2/TCO_2$ gap for various specific diagnoses. Mean TO_2 was not associated with any endpoint.

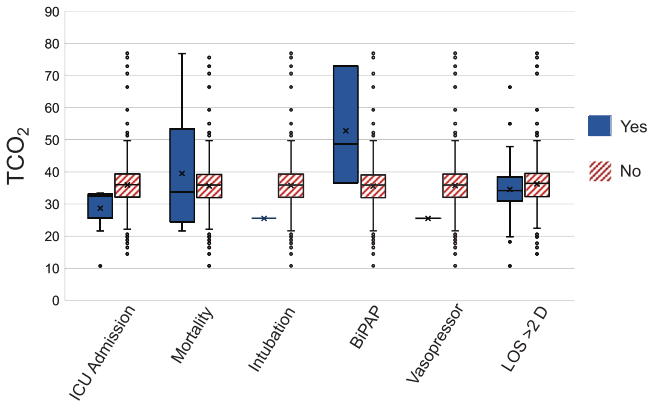


FIGURE 2 Transcutaneous CO_2 and clinical outcomes. Comparison of the measured TCO_2 measured at 15 minutes to clinical outcomes. Abbreviations: BiPAP, bilevel positive airway pressure; LOS, length of stay; TCO_2, transcutaneous carbon dioxide

4.3 | Correlation of TCO_2 and TO_2 with probe placement and data timing

The correlation coefficients and 95% confidence intervals comparing TCO_2, TO_2, and $ETCO_2$ measurements are reported in Figure 3. There was a strong positive correlation between centrally and peripherally placed TCO_2 probe measurements (r = 0.83). There was also a strong correlation between centrally and peripherally placed TO_2 probe measurements, though slightly less so (r = 0.57). A strong positive correlation was observed with both TCO_2 (r = 0.83) and TO_2 (r = 0.57) measurements taken at initial time versus steady state (15 minutes).

4.4 | Correlation of TO_2 and TCO_2 with other markers

There was a weak correlation between TO_2 and pulse oximetry (r = 0.25). A moderate correlation (r = 0.32) exists between TCO_2 and $ETCO_2$. The mean difference between $ETCO_2$ and TCO_2 was 3.7 mmHg. There were 30 subjects who had a discrepancy between $ETCO_2$ and TCO_2 of greater than 10 mmHg. These patients were older in age, averaging 67 versus 51 years, and more likely to have cardiorespiratory complaints than those with concordant values. Those with large disparate values also had a longer average LOS (3.4 days) compared to concordant values (1.6 days).

The mean TCO_2 was lower in patients with lactate > 2.0 mmol/L (29.8 mmHg, 95%CI 25.8–33.8) than those with lactate < 2.0 mmol/L (35.7 mmHg, 95% CI 34.9–36.9). The TCO_2 values of centrally placed probes for individual markers of severe illness are summarized in Table 2 and Figure 2. Notably, patients admitted to the ICU (N = 11) had a significantly lower average TCO_2 (28.7 mmHg) compared to those admitted to step down units or the floor (35.7 mmHg).

The correlation coefficient for patients who had an ABG completed at the time of central TCO_2 measurements (N = 9) demonstrated a strong positive linear relationship (r = 0.94) comparing ABG PCO_2 to

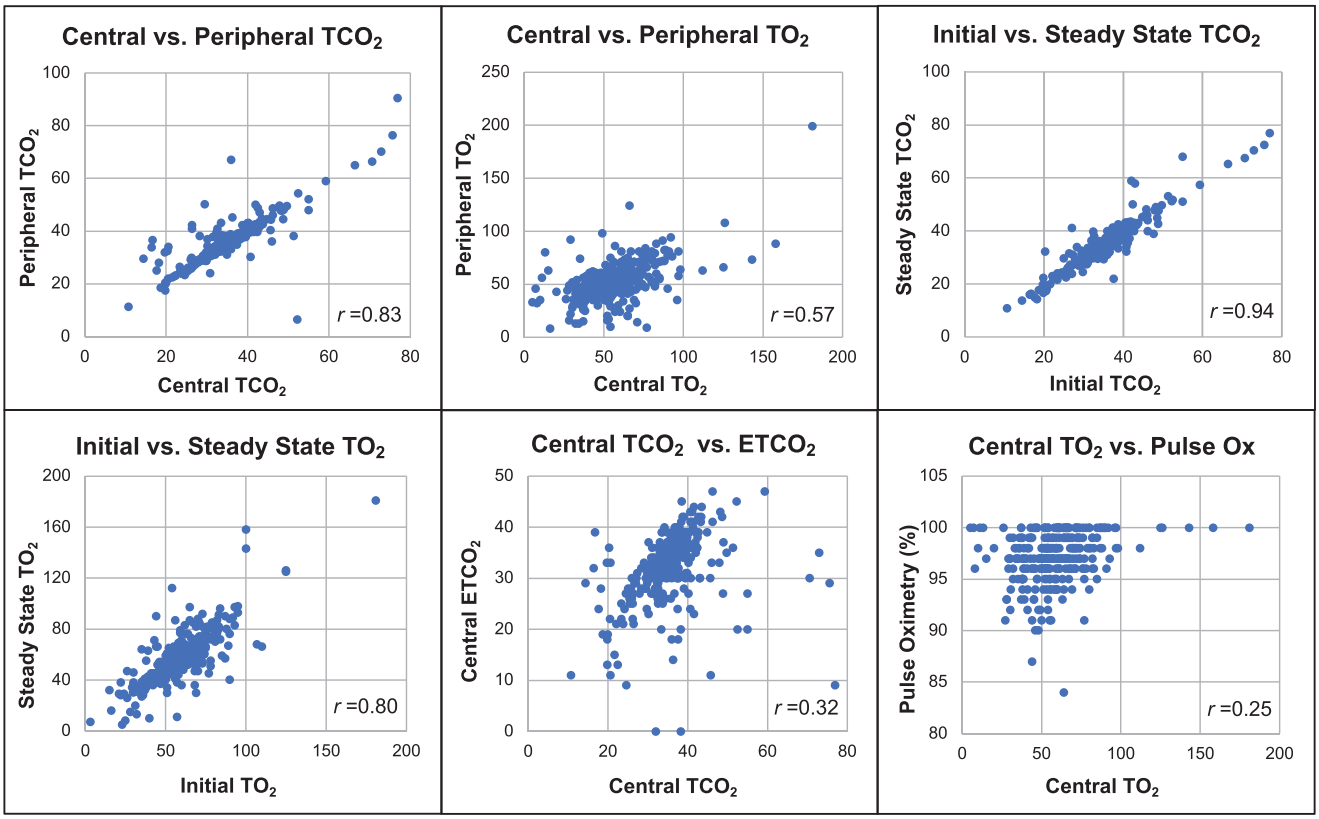


FIGURE 3 Correlation between secondary outcomes. Abbreviations: $ETCO_2$, end tidal carbon dioxide; TO_2, transcutaneous oxygen; TCO_2, transcutaneous carbon dioxide

TABLE 2 TCO_2 (mmHg) levels for the composite and individual outcomes

Outcome	Present		Not Present	
	N	TCO_2 (95% CI)	N	TCO_2 (95% CI)
Severe illness	106	34.6 (95% CI 33.0–36.2)	193	35.9 (95% CI 34.7–37.1)
Death†	6	39.5 (95% CI 18.4–60.6)	293	35.6 (95% CI 34.6–36.5)
ICU admission†	11	28.7 (95% CI 24.0–33.4)	288	35.7 (95% CI 34.7–36.7)
Endotracheal intubation†	1	25.5	298	35.7
BiPAP†	3	52.8 (95% CI 7.0–98.6)	296	35.5 (95% CI 34.6–36.4)
Admission > 2 days†	100	34.5 (95% CI 33.0–36.0)	199	36.2 (95% CI 35.0–37.5)
Vasopressor†	1	25.5	298	35.7
Lactate > 2 mmol/L	61	29.8 (95% CI 25.8–33.8)	238	35.7 (95% CI 34.9–36.9)

†For each individual outcome, the measurement is for all with that outcome compared to other study participants. Abbreviations: BiPAP, bilevel positive airway pressure; CO2, transcutaneous carbon dioxide

TCO_2. Correlation coefficient of $ETCO_2$ versus ABG PCO_2 showed a weak relationship (r = 0.11).

4.5 | Limitations

There are potential limitations to this study. The overall low number of mortalities, ICU admissions, intubations, and vasopressor use weakened the overall power as well as comparisons based on associated TCO_2 levels. The use of the severe illness definition as a composite outcome was intentionally chosen in order to increase the study power and the number of patients who may benefit from this non-invasive and continuous monitoring strategy. However, it also increased the likelihood of confounding variables. Our subgroup analysis, particularly ICU admission, demonstrated a significant difference with regard to TCO_2.

Further, this study was conducted on a convenience sample, with patients enrolled typically during the daytime regardless of chief complaint. This made it difficult to determine if there was a correlation

TABLE 3 Mean TCO_2 measurements and $ETCO_2/TCO_2$ for specific disease processes

	N	ETCO2	Mean TCO_2 (mmHg)	$ETCO_2$ - TCO_2 gap (mmHg)
All cardiorespiratory	21	29.7 (95% CI 26.6–32.7)	40.1 (95% CI 37.0–43.3)	9.8
Pulmonary embolus	3	28.3 (95% CI 19.5–37.2)	39.9 (95% CI 36.7–43.1)	12.1
Asthma/chronic obstructive pulmonary disease	7	27.0 (95% CI 20.8–33.2)	41.7 (95% CI 38.9–44.5)	15.1
Congestive heart failure	7	31.7 (95% CI 29.0–34.4	39.3 (95% CI 30.6–48.0)	4.8
Pneumonia	4	31.8 (95% CI 24.8–38.7)	38.9 (95% CI 37.0–40.8)	7.1
Sepsis/infection	4	27.9 (95% CI 23.5–32.3)	29.9 (95% CI 27.1–32.8)	4.7

Abbreviations: ETCO2, end tidal carbon dioxide; TCO2, transcutaneous carbon dioxide

between TCO_2 measurements and specific disease processes. It is possible that cardiorespiratory illnesses or sepsis may have a greater change in TCO_2 than other conditions that lead to hospitalization. In future studies, it would be of interest to assess patients with specific conditions or diseases to increase the power and applicability of the technology.

5 | DISCUSSION

Although transcutaneous measurements of oxygen and carbon dioxide have been used in other settings, their utility in the ED is still under investigation. In this prospective assessment we found that TO_2 and TCO_2 did not discriminate for the composite outcome of severe illness. However, TCO_2 could be a useful adjunct for identifying critically ill patients in an ED population, on average lower in those admitted to ICU compared to other dispositions. There was a strong correlation between TCO_2 values taken initially and at steady state. TCO_2 is only moderately correlated with $ETCO_2$ but is strongly correlated with lactate and $PaCO_2$.

This is not the first study to examine the utility of TCO_2 in an ED population. Tatevossian et al. examined the use of TCO_2 in trauma patients with signs of shock.[9] In that study, non-survivors had lower TO_2 and higher TCO_2 compared with survivors. However, that was the only other study to correlate transcutaneous measurements with outcomes in an ED population and included only critically ill trauma patients.

TCO_2 or TO_2 were not statistically different between ED patients with severe and non-severe illness as a whole. When considering individual markers of severe illness, patients with ICU admission had a significantly lower TCO_2. However, the enrollment time frame captured only a limited number of patients who were admitted to the ICU. Additionally, only a few patients were critically ill trauma patients with signs of shock, which could explain the discrepancy in results from Tatevossian et al.[9] Future studies should replicate this result by recruiting more critically ill patients with a wide range of etiologies, not solely trauma.

When using a transcutaneous monitor, it is clear that centralized (torso and head) probe locations are more accurate than using peripheral (arm or leg) for measuring TCO_2. Less variation was seen in central locations. In a few patients a warmup period was necessary to reach steady state. However, the majority of initial values were similar to steady state and exhibited a strong correlation. It is theorized that any discrepancies could be because of the perfusion differences in distal capillary beds, particularly in septic, hypothermic, or hypotensive patients experiencing peripheral vasoconstriction.

The utility of $ETCO_2$ and lactate have been well established in an ED setting.[11–16] Likewise, $ETCO_2$ has been shown to have a strong negative correlation with lactate in patients with suspected sepsis.[11] In this study, TCO_2 and $ETCO_2$ measurements had a moderate correlation. This is reasonable considering that venous $PaCO_2$ and $ETCO_2$ are not the comparable measurements. There was a weak correlation between TO_2, which correlates to the venous PaO_2, and pulse oximetry. These discrepancies illustrate that the transcutaneous data are not a duplication of these other non-invasive measures but may add useful information to guide management.

The TCO_2 and lactate had a moderate correlation. Additionally, patients with lactate >2 mmol/L had lower TCO_2 than patients with lactate <2 mmol/L. This suggests that in a pool of patients with suspected sepsis in which lactate would be drawn, TCO_2 could be a useful non-invasive tool to predict severe illness. Future studies should focus solely on a sample of patients with suspected sepsis.

The correlation between $PaCO_2$ and TCO_2 has been established in ED settings, specifically in patients with acute respiratory failure.[17–22] Lermuzeaux et al. showed that TCO_2 had a stronger correlation with $PaCO_2$ than $ETCO_2$ in these patients, which could be because of the increase in alveolar dead space that artificially lowers $ETCO_2$ compared with $PaCO_2$.[18] This study replicated these results, showing that TCO_2 had a stronger correlation with $PaCO_2$ than $ETCO_2$. Also, patients with a large discrepancy between $ETCO_2$ and TCO_2 were more likely to have cardiorespiratory complaints (ie, chronic obstructive pulmonary disease, asthma, pneumonia, pulmonary embolism), further suggesting that alveolar dead space could play a role.

In summary, TCO_2 could be a useful adjunct for identifying severe illness in an ED population. However, we found that TO_2 and TCO_2 did not discriminate for our composite outcome of severe illness. On average, it was lower in those admitted to ICU compared to other dispositions, illustrating the potential for identification of critically ill patients. Initial measurements in a central location appear to be the most optimal and efficient methods of measurement. TCO_2 is strongly

correlated with lactate and $PaCO_2$ but moderately correlated with $ETCO_2$. The discrepancy suggests that the data are not a duplication of other non-invasive measures but may add useful information to guide management. TO_2 did not predict severity of illness in this population. TCO_2 and $ETCO_2$ could be useful in unique circumstances in an ED, such as cardiorespiratory complaints and suspected sepsis. Future studies in the ED, including larger subsets of patients with specific disease processes, would be of interest to assess the potential utility and applicability of the technology.

CONFLICTS OF INTEREST

No conflicts of interest for any author.

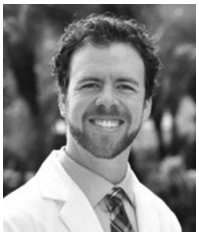
AUTHOR CONTRIBUTIONS

JT, LP, and JL conceived and planned the study. AC, KL, LN, and JM acquired the data. MB compiled and analyzed the dataset, with support from JT, LP, LN, and KL. All authors contributed to the interpretation of the results. MB wrote the manuscript with support from JT. All authors provided critical feedback and helped shape the research, analysis and manuscript.

REFERENCES

1. Trzeciak S, Dellinger RP, Chansky ME. Serum lactate as a predictor of mortality in patients with infection. *Intensive Care Med*. 2007;33(6):970-977.
2. Abramson D, Scalea TM, Hitchcock R, Trooskin SZ, Henry SM, Greenspan J. Lactate clearance and survival following injury. *J Trauma*. 1993;35(4):588-589.
3. Wayne MA, Levine RL, Miller CC. Use of end-tidal carbon dioxide to predict outcome in prehospital cardiac arrest. *Ann Emerg Med*. 1995;25(6):762-767.
4. Hunter CL, Silvestri S, Ralls G, Stone A, Walker A, Papa L. A prehospital screening tool utilizing end-tidal carbon dioxide predicts sepsis and severe sepsis. *Am J Emerg Med*. 2016;34(5):813-819.
5. 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.
6. Stone ME Jr, Kalata S, Liveris A. End-tidal CO2 on admission is associated with hemorrhagic shock and predicts the need for massive transfusion as defined by the critical administration threshold: a pilot study. *Injury*. 2017;48(1):51-57.
7. Bolliger D, Steiner LA, Kasper J, Aziz OA, Filipovic M, Seeberger MD. The accuracy of non-invasive carbon dioxide monitoring: a clinical evaluation of two transcutaneous systems. *Anaesthesia*. 2007;62(4):394-399.
8. van Weteringen W, Goos TG, van Essen T. Novel transcutaneous sensor combining optical tcPO2 and electrochemical tcPCO2 monitoring with reflectance pulse oximetry. *Med Biol Eng Comput*. 2020;58(2):239-247.
9. Tatevossian RG, Wo CC, Velmahos GC, Demetriades D, Shoemaker WC. Transcutaneous oxygen and CO2 as early warning of tissue hypoxia and hemodynamic shock in critically ill emergency patients. *Crit Care Med*. 2000;28(7):2248-2253.
10. Tremper KK, Shoemaker WC. Transcutaneous oxygen monitoring of critically ill adults, with and without low flow shock. *Crit Care Med*. 1981;9(10):706-709.
11. 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.
12. Kartal M, Eray O, Rinnert S, Goksu E, Bektas F, Eken C. ETCO(2): a predictive tool for excluding metabolic disturbances in nonintubated patients. *Am J Emerg Med*. 2011;29(1):65-69.
13. Kheng CP, Rahman NH. The use of end-tidal carbon dioxide monitoring in patients with hypotension in the emergency department. *Int J Emerg Med*. 2012;5(1):31.
14. Silvestri S, Ralls GA, Krauss B. 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.
15. Childress K, Arnold K, Hunter C, Ralls G, Papa L, Silvestri S. Prehospital end-tidal carbon dioxide predicts mortality in trauma patients. *Prehosp Emerg Care*. 2018;22(2):170-174.
16. Oedorf K, Day DE, Lior Y. Serum lactate predicts adverse outcomes in emergency department patients with and without infection. *West J Emerg Med*. 2017;18(2):258-266.
17. Bobbia X, Claret PG, Palmier L. Erratum: concordance and limits between transcutaneous and arterial carbon dioxide pressure in emergency department patients with acute respiratory failure: a single-center, prospective, and observational study. *Scand J Trauma Resusc Emerg Med*. 2015;23:77.
18. Lermuzeaux M, Meric H, Sauneuf B. Superiority of transcutaneous CO2 over end-tidal CO2 measurement for monitoring respiratory failure in nonintubated patients: a pilot study. *J Crit Care*. 2016;31(1):150-156.
19. McVicar J, Eager R. Validation study of a transcutaneous carbon dioxide monitor in patients in the emergency department. *Emerg Med J*. 2009;26(5):344-346.
20. Rodriguez P, Lellouche F, Aboab J, Buisson CB, Brochard L. Transcutaneous arterial carbon dioxide pressure monitoring in critically ill adult patients. *Intensive Care Med*. 2006;32(2):309-312.
21. Gancel PE, Roupie E, Guittet L, Laplume S, Terzi N. Accuracy of a transcutaneous carbon dioxide pressure monitoring device in emergency room patients with acute respiratory failure. *Intensive Care Med*. 2011;37(2):348-351.
22. Delerme S, Montout V, Goulet H. Concordance between transcutaneous and arterial measurements of carbon dioxide in an ED. *Am J Emerg Med*. 2012;30(9):1872-1876.

AUTHOR BIOGRAPHY



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