Utility of Prehospital Quantitative End Tidal CO_2?

Christopher J. Cooper, MD;[1] James J. Kraatz, MD FACS;[2] David S. Kubiak, MHA;[3] James W. Kessel, MD FACS;[1] Stephen L. Barnes, MD FACS[1]

1. Acute Care Surgery, University of Missouri, Columbia, Missouri USA
2. Bronson Trauma Surgery Services, Kalamazoo, Michigan USA
3. Burn and Wound Program, University of Missouri, Columbia, Missouri USA

Correspondence:
Christopher J. Cooper MD
Division of Acute Care Surgery
University of Missouri
One Hospital Drive, MC205
Columbia, MO 65203 USA
E-mail: coopercj@health.missouri.edu

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Abbreviations:
ABG: Arterial Blood Gas
EMS: Emergency Medical System
$ETCO_2$: End tidal carbon dioxide
GCS: Glasgow Coma Score
ICU: Intensive Care Unit
IQR: Interquartile Range
ISS: Injury Severity Score
LTAC: Long Term Acute Care Hospital
LOS: Length of Stay
$PACO_2$: Partial pressure of arterial carbon dioxide
RTS: Revised Trauma Score
SD: Standard Deviation
SNF: Skilled Nursing Facility
TBI: Traumatic Brain Injury
TRISS: Trauma Injury Severity Score

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Abstract

Introduction: End tidal CO_2 ($ETCO_2$) has been established as a standard for confirmation of an airway, but its role is expanding. In certain settings $ETCO_2$ closely approximates the partial pressure of arterial CO_2 ($PaCO_2$) and has been described as a tool to optimize a patient's ventilatory status. $ETCO_2$ monitors are increasingly being used by EMS personnel to guide ventilation in the prehospital setting. Severely traumatized and burn patients represent a unique population to which this practice has not been validated.

Hypothesis: The sole use of $ETCO_2$ to monitor ventilation may lead to avoidable respiratory acidosis.

Methods: A consecutive series of patients with burns or trauma intubated in the prehospital setting over a 24-month period were evaluated. Prehospital arrests were excluded. Absence of $ETCO_2$ transport data and patients without an arterial blood gas (ABG) within 15 minutes of arrival were also excluded. Data collected included demographics, place and time of intubation, service performing intubation, $ETCO_2$ maintained en-route to hospital, and ABG upon arrival. Further data included length of stay, mortality, and injury severity scores.

Results: One hundred sixty patients met the inclusion criteria. Prehospital $ETCO_2$ did not correlate with measured $PaCO_2$ ($R^2 = 0.08$). Mean $ETCO_2$ was significantly lower than mean $PaCO_2$ (34 mmHg vs 44 mmHg, $P < .005$). Patients arriving acidotic were more likely to die. Mean pH on arrival for survivors and decedents was 7.32 and 7.19 respectively ($P < .001$). Mortality, acidosis, higher base deficits, and more severe injury patterns were all predictors for a worse correlation between $ETCO_2$ and $PaCO_2$ and increased mean difference between the two values. Decedents and patients presenting with a pH <7.2 demonstrated the greatest discrepancy between $ETCO_2$ and $PaCO_2$. The data suggest that patients may be hypoventilated by prehospital providers in order to obtain a prescribed $ETCO_2$.

Conclusion: $ETCO_2$ is an inadequate tool for predicting $PaCO_2$ or optimizing ventilation in severely injured patients. Adherence to current $ETCO_2$ guidelines in the prehospital setting may contribute to acidosis and increased mortality. Consideration should be given to developing alternate protocols to guide ventilation of the severely injured in the prehospital setting.

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Introduction

End tidal CO_2 ($ETCO_2$) monitoring provides a non-invasive assessment of a patient's ventilatory status and its application has been well established in certain clinical scenarios. It is the standard of care for clinical monitoring of adult and pediatric patients undergoing general anesthesia,[1-3] is used extensively in the intensive care unit to monitor mechanical ventilation,[4,5] and is widely accepted as a critical tool to confirm proper endotracheal intubation and airway patency.[6,7] Capnography has also been extensively utilized and validated in the prehospital setting for patients requiring cardiopulmonary resuscitation and emergency cardiovascular care.[8,9] In the post-operative setting, $ETCO_2$ has been used to detect sedation-induced hypoventilation, bronchospasm, and apnea.[10,11] Many studies have also demonstrated a close correlation between $ETCO_2$ and the partial pressure of arterial CO_2 ($PaCO_2$) in certain patient populations.[12-14] As a result, $ETCO_2$ monitoring is increasingly being used by emergency medical providers in the prehospital setting to guide ventilation as a substitute for serial $PaCO_2$.[15]

Early and effective management of the acutely injured patient to avoid hypotension and hypoxia are of paramount importance in reducing morbidity and mortality. Proper ventilation strategies for those patients intubated in the prehospital setting improves their outcome, especially for those suffering from traumatic brain injuries (TBIs).[16] It has been suggested that the ideal range for $PaCO_2$ during early ventilation of the traumatized patient is between 30mm Hg and 39 mm Hg.[17] This prevents significant hypercapnea as well as hypocapnea, both of which have detrimental effects on cerebral perfusion and secondary brain injury following TBI.[18] Due to the limited capability for prehospital providers to perform serial $PaCO_2$, many emergency medical system (EMS) protocols advocate for the titration of ventilation by keeping $ETCO_2$ values between 30 mm Hg and 35 mm Hg.[19] This is based upon the close correlation of $ETCO_2$ to $PaCO_2$[12-14] and the observation that $PaCO_2$ is predictably 2 mm Hg to 5 mm Hg above $ETCO_2$ values.[20]

The physiology and injury pattern of severely traumatized and thermally injured patients represent a unique population to which the use of $ETCO_2$ monitoring as a surrogate of $PaCO_2$ to guide ventilation has not been validated. $ETCO_2$ values are significantly affected in the setting of ventilation-perfusion mismatch, increased dead space, and poor perfusion as a result of hypovolemic shock,[21,22] all potential physiologic changes recognized in the trauma or burn patient. The hypothesis for this study was $ETCO_2$ does not correlate with $PaCO_2$ in the trauma and burn victim, and adherence to current guidelines to keep $ETCO_2$ between 30 mm Hg and 35 mm Hg is associated with avoidable respiratory acidosis.

Methods

An institutional review board-approved, prospective observational study was performed over a 24-month period for trauma and burn patients intubated and transferred to a University Level I trauma and dedicated burn center. Patients were included in the study if they were intubated in the prehospital setting following a traumatic or burn-related injury and directly transported to the trauma and burn center. Absence of $ETCO_2$ transport data and patients without an ABG within 15 minutes of arrival to the trauma center were excluded. Prehospital arrests and patients age <18 were also excluded.

On arrival to the trauma center, $ETCO_2$ data was obtained immediately from the emergency medical providers involved in transporting the patient. The $ETCO_2$ values maintained en route to the hospital were recorded. After arrival to the trauma center, minute ventilation was continued based on $ETCO_2$ and not adjusted until obtaining an arterial blood gas (ABG). Patients underwent arterial puncture by the respiratory therapist after completion of the primary survey for obtaining an arterial blood gas (ABG). The place and time of the intubation as well as the service performing the intubation was recorded from the documentation provided from the transporting medics. Additional data collected included the demographics of the patients, prehospital Glasgow Coma Score (GCS), hospital and Intensive Care Unit (ICU) length of stay, and mortality. Injury severity patterns of the patients were classified based on the Injury Severity Score (ISS), Trauma Injury Severity Score (TRISS), and Revised Trauma Score (RTS), which were obtained from the trauma registry. The discharge disposition of the survivors was also obtained from the trauma registry.

The mean difference between prehospital $ETCO_2$ and arrival $PaCO_2$ was compared across the cohort to determine statistical significance, and linear regression analysis was used to determine the degree of correlation between the two values. A subgroup analysis was performed to examine the difference between survivors and decedents, those with a pH <7.2 and pH ≥7.2, arterial base deficits ≥6 and <6, patients with ISS ≥25, ≥15, and <15, and RTS ≤4 and >4. Survivors were defined as those patients discharged from the hospital alive, regardless of discharge disposition. Decedents were defined as those patients who died after arrival to the trauma center.

Statistical analysis was conducted using Microsoft Excel Version 14.0.476 (Microsoft Corporation, Redmond, Washington, USA). The differences between $ETCO_2$ and $PaCO_2$ were analyzed using a student *t*-test. Statistical significance was determined at a *P* value less than .05. Linear regression analysis was utilized to evaluate the correlation between $ETCO_2$ and $PaCO_2$ values.

Demographics (N = 160)	n (%) or Mean (SD)
Gender	
Male	122 (76)
Female	38 (24)
Age	
Mean Overall	42 (19)
Mean (Male)	40 (18)
Mean (Female)	49 (22)
Injury Mechanism	
Trauma	139 (87)
Burn	21 (13)
Outcome	
Survivors	126 (79)
Decedents	34 (21)

Table 1. Demographics and Patient Characteristics

Results

One hundred sixty patients met the inclusion criteria. The mean age was 42 (SD = 19) with a predominantly male population (76%) (Table 1). One hundred thirty-nine (87%) of the patients suffered a severe trauma, while 21 (13%) of patients had strictly burn-related injuries requiring intubation (Table 1). Thirty-four (21%) of the patients died after arrival to the trauma center (Table 1). The overwhelming majority of patients (75%) had a pre-intubation GCS <8, and over half had ISS ≥15 (52%) and RTS ≤4 (52%) (Table 2). Twenty-nine percent of the study population fell into the most severe injury classification with ISS ≥25 and over one-third of the entire study had TRISS scores <0.50 (Table 2). The decedents had a predictably shorter hospital and ICU stay when compared with survivors, who averaged an extensive 48 (SD = 16) day hospital stay and 10 (SD = 52) days in the ICU (Table 3). Of the survivors, 110 (88%) were able to be discharged home or to a rehabilitation facility, with a small percentage progressing to a long term acute

Injury Severity Classification	n (%)
Pre-hospital GCS	
14-15	26 (16)
9-13	14 (9)
≤8	120 (75)
ISS	
≥25	46 (29)
≥15	83 (52)
TRISS	
0-0.25	35 (22)
0.26-0.50	21 (13)
0.51-0.75	40 (25)
0.76-1	64 (40)
RTS	
≤4	83 (52)

Table 2. Injury Severity Patterns (N = 160)
Abbreviations: GCS, Glasgow Coma Score; ISS, Injury Severity Score; TRISS, Trauma Injury Severity Score; RTS, Revised Trauma Score

Subgroups	Mean (SD)	Median (IQR)
Decedents (n = 34)		
Hospital LOS	6 (8)	1.5 (5.5)
ICU LOS	5 (8)	1.5 (5.5)
Survivors (n = 126)		
Hospital LOS	48 (16)	11 (18)
ICU LOS	10 (52)	5 (12)
Disposition for Survivors	**n (%)**	
Home, no assist	63 (50)	
Home, with assist	5 (4)	
Rehabilitation Facility	42 (34)	
LTAC	5 (4)	
SNF	3 (2)	
Other	8 (6)	

Table 3. Outcome Data
Abbreviations: SD, Standard Deviation; IQR, Interquartile Range; LOS, Length of Stay; ICU, Intensive Care Unit; LTAC, Long Term Acute Care Hospital; SNF, Skilled Nursing Facility

care hospital (LTAC) (4%) or skilled nursing facility (SNF) (2%) (Table 3).

Those patients who ultimately died were correspondingly more acidotic with a mean arrival pH of 7.19 (SD = 0.14) versus survivors with a mean arrival pH of 7.32 (SD = 0.11) ($P < .001$). Overall mean prehospital $ETCO_2$ (34 (SD = 4) mm Hg) was significantly lower than mean arrival $PaCO_2$ (44 (SD = 11) mm Hg) ($P < .005$), and did not reveal a correlation after linear regression analysis ($R^2 = 0.08$) (Table 4, Figure 1). The analysis between the survivor and decedent populations revealed an even greater difference between $ETCO_2$ and $PaCO_2$. Decedents did not demonstrate a difference between $ETCO_2$ and $PaCO_2$ ($R^2 = 0.0002$) and mean measured $PaCO_2$ was 17 mm Hg higher than $ETCO_2$ ($P < .003$, Table 4, Figure 2). In comparison, survivors had an $ETCO_2$ and $PaCO_2$ correlation coefficient of 0.34 with a mean difference of 7 mm Hg ($P > .05$, Table 4, Figure 2).

When examining the sub group analysis of those patients with a pH of less than 7.2, there was a poor correlation and larger difference between $ETCO_2$ and $PaCO_2$ when compared to those patients with a pH ≥7.2 (Table 4, Figures 3a and 3b). For patients with a pH <7.2, $ETCO_2$ measurements were on average 20 mm Hg less then matched $PaCO_2$ values ($p < 0.001$) with no evidence of correlation (Figure 3a, $R^2 = 0.0005$). Patients with an arrival pH of ≥7.2 did not demonstrate a correlation between $ETCO_2$ and $PaCO_2$ (Figure 3b, $R^2 = 0.34$), but there was not a statistically significant difference between the two values with a mean difference of 7 mm Hg (Table 4).

Patients with higher arterial base deficits also demonstrated an increased mean difference between $ETCO_2$ and $PaCO_2$ with a correspondingly worse correlation when compared to patients with less significant base deficits. Those patients with a base deficit ≥6 had a significantly lower $ETCO_2$ compared to $PaCO_2$ with a mean difference of 11 mm Hg ($P < .05$) and correlation coefficient of 0.061 (Table 4, Figure 4). Although patients with a base deficit of <6 did not demonstrate a correlation between prehospital $ETCO_2$ and arrival $PaCO_2$ ($R^2 = 0.11$), there was a non-significant difference between the means ($P > .05$) (Table 4, Figure 4).

Those patients suffering the most severe injuries, based on an ISS of ≥25 and RTS ≤4, revealed the greatest difference between $ETCO_2$ and $PaCO_2$ when compared to those with less severe injury patterns, based on an ISS of <15 and RTS >4 (Table 4). Patients with an ISS ≥25 and RTS ≤4 had a mean difference of 11 mm Hg ($P < .05$) and no evidence of correlation between prehospital $ETCO_2$ and measured $PaCO_2$ ($R^2 = 0.0003$ and 0.0002 respectively, Table 4). In contrast, patients with ISS <15 and RTS >4 did not have a significant difference between mean $ETCO_2$ and $PaCO_2$ scores (7 and 6 mm Hg respectively) and had better correlation coefficient scores ($R^2 = 0.46$ and 0.51 respectively, Table 4).

Discussion

$ETCO_2$ monitoring is a simple, non-invasive modality that has numerous clinical applications. Well established as an accurate tool for monitoring a patient's ventilatory status during routine general anesthesia and confirming placement of an airway after endotracheal intubation, its role has expanded.[1-3,6,7] With several studies demonstrating a strong correlation between $ETCO_2$ and $PaCO_2$,[12-14] the use of continuous $ETCO_2$ monitoring to guide

Subgroup	n	$ETCO_2$ Mean (SD)	$PaCO_2$ Mean (SD)	$ETCO_2$:$PaCO_2$	R^2
Overall	160	34 (4)	44 (11)	10[a]	0.08
Survivors	126	35 (3)	42 (9)	7	0.34
Decedents	34	32 (6)	49 (16)	17[a]	0.0002
Trauma	139	34 (4)	43 (11)	9[a]	0.06
Burn	21	36 (3)	44 (11)	8[a]	0.31
pH <7.2	22	35 (8)	55 (18)	20[a]	0.0005
pH ≥7.2	138	34 (3)	41 (8)	7	0.34
Arterial base deficit ≥6	60	32 (6)	43 (11)	11[a]	0.061
Arterial base deficit <6	100	34 (3)	42 (11)	8	0.11
ISS ≥25	46	33 (6)	44 (13)	11[a]	0.0003
ISS ≥15	83	34 (5)	43 (11)	9[a]	0.004
ISS <15	77	34 (3)	41 (9)	7	0.46
RTS ≤4	83	34 (5)	45 (12)	11[a]	0.0002
RTS >4	77	33 (3)	39 (9)	6	0.51

Table 4. Mean End Tidal to Arterial CO_2 Difference
Abbreviations: $ETCO_2$, mean end tidal CO_2 in mm Hg; $ETCO_2$: $PaCO_2$, absolute mean difference between end tidal and arterial CO_2; ISS, Injury Severity Score; $PaCO_2$, mean partial pressure of arterial CO_2 in mm Hg; R^2, correlation coefficient using linear regression; RTS, Revised Trauma Score
[a]$P < .05$

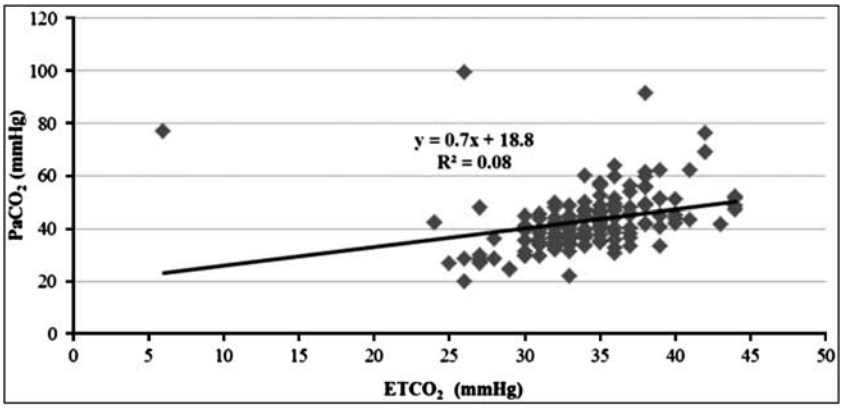

Figure 1. Overall Prehospital $ETCO_2$ Values Plotted Against Paired Arrival $PaCO_2$ Values. Linear regression analysis demonstrates best fit line with R^2 coefficient correlation.
Abbreviations: $ETCO_2$, end tidal CO_2; $PaCO_2$, partial pressure of arterial CO_2

ventilation in the prehospital setting is replacing guidelines that focus on fixed ventilator parameters.[15] Some EMS protocols and guidelines have established pre-determined $ETCO_2$ ranges to be maintained while transporting the intubated patient to a trauma center.[19] It is an attractive option in this setting where frequent ABG sampling is not feasible or practical. However, most of the data that correlates $ETCO_2$ and $PaCO_2$ is based on healthy patients,[12] which creates a potential discrepancy for the severely traumatized patient.[15,23,24]

Inappropriate prehospital ventilation can have devastating consequences on the long term morbidity and mortality of the trauma patient. This is particularly true for the patients sustaining a TBI and presenting with significant hypercapnea or hypocapnea as a result of poor ventilation.[16,18] Maintaining $PaCO_2$ levels between 30-39 mm Hg in the prehospital setting has been linked to a significant survival advantage and better outcomes in the trauma and burn patient.[17,19] In order to optimize prehospital care in this population, the correlation between prehospital $ETCO_2$

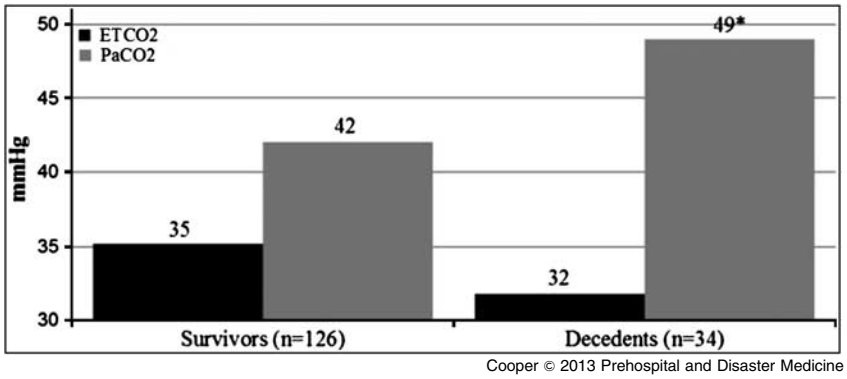

Figure 2. Mean Difference of Prehospital $ETCO_2$ and Arrival $PaCO_2$ Values for Survivors and Decedents.
Abbreviations: $ETCO_2$, end tidal CO_2; $PaCO_2$, partial pressure of arterial CO_2
n = total number
*$P < .05$

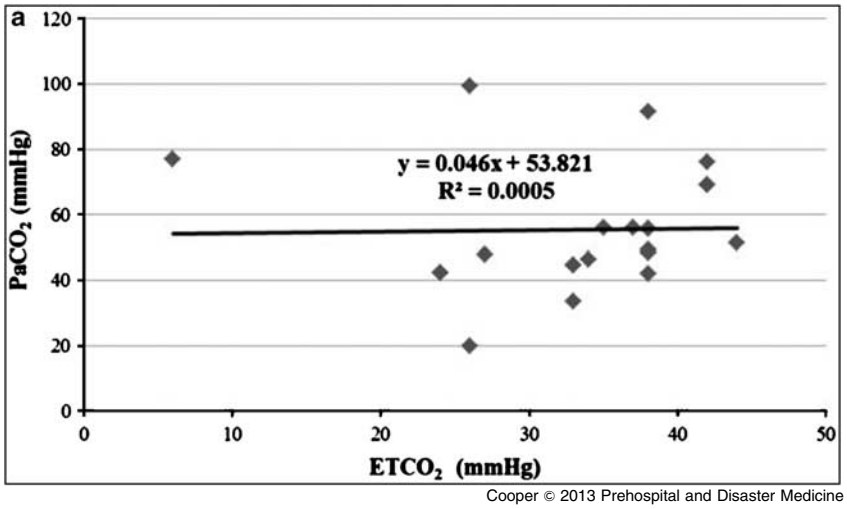

Figure 3a. Patients Presenting with a pH Below 7.2 and Corresponding Prehospital $ETCO_2$ Values Plotted Against Paired Arrival $PaCO_2$ Values. Linear regression analysis demonstrates best fit line with R^2 coefficient correlation.
Abbreviations: $ETCO_2$, end tidal CO_2; $PaCO_2$, partial pressure of arterial CO_2

and measured $PaCO_2$ in the severely traumatized patient was evaluated to determine if accurate ventilation was being provided based on EMS guidelines.

The results indicate no correlation between $ETCO_2$ and $PaCO_2$ in the severely injured trauma and burn patient. When looking at the overall study population, mean prehospital $ETCO_2$ was significantly lower than arrival $PaCO_2$ and there was no evidence of correlation between the two means. The examination of the subgroup analysis between outcomes, patient characteristics, physiologic status, and injury severity patterns revealed some alarming trends in the difference between prehospital $ETCO_2$ and measured $PaCO_2$. Mortality, acidosis, higher base deficits, and more severe injury patterns were associated with a greater discrepancy between $ETCO_2$ and $PaCO_2$. This discrepancy and lack of correlation was most evident in the acidotic patient presenting with a pH <7.2 and in those patients who ultimately died. The injury severity classifications also demonstrated a trend in $ETCO_2$ and $PaCO_2$ differences. Those patients presenting with a base deficit ≥6, an ISS ≥25, and RTS ≤4 all had exaggerated differences between $ETCO_2$ and $PaCO_2$ and no evidence of correlation based on linear regression analysis (Table 4).

In comparison, patients with less severe injury patterns and better physiologic arrival parameters demonstrated a more favorable correlation between $ETCO_2$ and $PaCO_2$. The difference between prehospital $ETCO_2$ and measured arrival $PaCO_2$ for those patients with a pH ≥7.2, an ISS <15, and RTS >4 never reached statistical significance, but still remained outside the "accepted difference" of 2 to 5 mm Hg.[20] The subgroup with RTS >4 came closest to the accepted difference and had the strongest correlation among all of the subgroups. This may provide some support to the previously published results indicating a correlation between $ETCO_2$ and $PaCO_2$ in healthier adults.[12-14] However, given the study population and results, there is no conclusive evidence that $ETCO_2$ can accurately predict $PaCO_2$, regardless of a patient's physiologic status or injury pattern; this diverges with severity of injury. Determining this point where the difference between $ETCO_2$ and $PaCO_2$ sharply diverges, based on GCS, injury pattern, and other easily obtainable physiologic parameters in the field, should be the focus for future studies. This could lead to the development of a prehospital scoring system that would alert prehospital providers when the use of $ETCO_2$ is ill advised and would lead to worse outcomes for the patient.

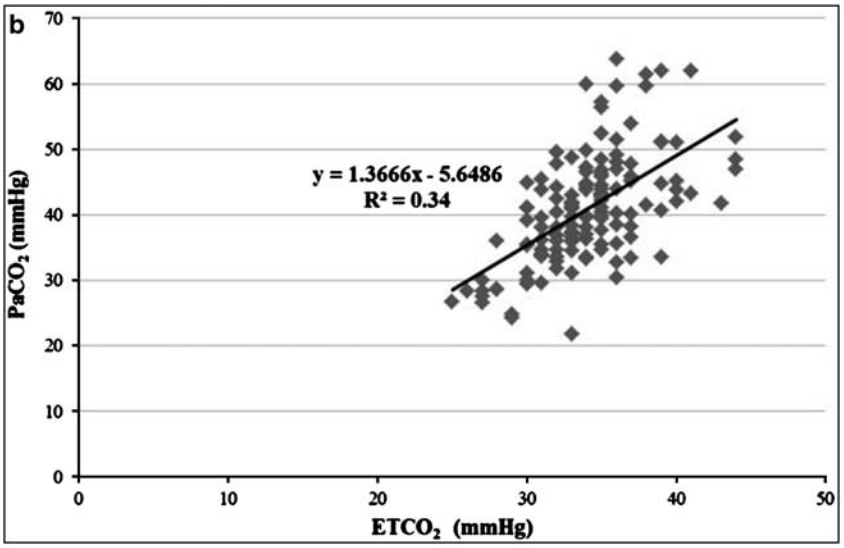

Figure 3b. Patients Presenting with a pH ≥ 7.2 and Corresponding Prehospital $ETCO_2$ Values Plotted against Paired Arrival $PaCO_2$ Values. Linear regression analysis demonstrates best fit line with R^2 coefficient correlation.
Abbreviations: $ETCO_2$, end tidal CO_2; $PaCO_2$, partial pressure of arterial CO_2

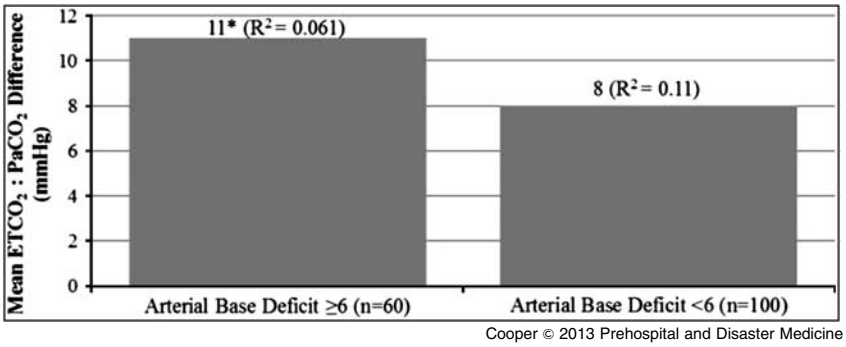

Figure 4. Mean $ETCO_2$: $PaCO_2$ Difference for Patients Presenting with an Arterial Base Deficit ≥6 and <6.
R^2 represents coefficient correlation after linear regression analysis; n = total number of patients.
Abbreviations: $ETCO_2$, end tidal CO_2; $ETCO_2$: $PaCO_2$, absolute mean difference between end tidal and arterial CO_2; $PaCO_2$, partial pressure of arterial CO_2
*$P < .05$

The results expose a problem in the management of prehospital ventilation for the trauma or burn patient if $ETCO_2$ is used as a surrogate for serial $PaCO_2$. $ETCO_2$ does not accurately predict $PaCO_2$ in the traumatized patient and its use as the sole modality for guiding ventilation may lead to hypoventilation. This is especially true in the more acidotic patient, which represents a subgroup where immediate and proper ventilation is even more critical to improving their outcomes. Blind adherence to current EMS guidelines to keep $ETCO_2$ within a prescribed range for all patients, regardless of physiologic state, may contribute to acidosis and increased mortality.

Limitations

The current study does have several limitations. This single institution analysis was limited to two years and a sample size of 160 patients. Therefore, the reproducibility of the results based on an experience in a limited environment cannot be attested. There was also variable lag time between the acquisition of an ABG and the recorded prehospital $ETCO_2$ value, which may obscure the ability to accurately assess the correlation between $ETCO_2$ and $PaCO_2$ using a linear regression analysis.

Conclusion

$ETCO_2$ correlates poorly with $PaCO_2$ in the traumatized patient and becomes increasingly inaccurate with severity of injury. The sole use of $ETCO_2$ monitoring to guide prehospital ventilation should be abandoned. Alternate protocols and tools should be developed to guide ventilation in the prehospital setting.

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