Utility of venous blood gases in severe sepsis and septic shock

Heath D. White, DO, MS ^a, Alfredo Vazquez-Sandoval, MD ^a, Pedro F. Quiroga, MD ^b, Juhee Song, PhD^c, Shirley F. Jones, MD ^a, and Alejandro C. Arroliga, MD, MS ^a

^aDivision of Pulmonary, Critical Care, and Sleep Medicine, Baylor Scott & White Health, Temple, Texas; ^bDivision of Pulmonary and Critical Care Medicine, Maricopa Medical Center, Phoenix, Arizona; ^cDepartment of Biostatistics, Baylor Scott & White Health, Temple, Texas

ABSTRACT

Acid-base status is frequently assessed in severe sepsis and septic shock. Venous blood gas sampling is proposed as a less-invasive modality but lacks evidence within this population. The objective of this study was to evaluate the correlation and agreement between arterial blood gas (ABG), peripheral venous blood gas (pVBG), and central venous blood gas (cVBG) in severe sepsis and septic shock. We conducted a prospective, observational cohort study in subjects admitted to the medical intensive care unit. Simultaneous blood gas samples, including ABG, pVBG, and cVBG, were analyzed for correlation and agreement. Severity of illness scores revealed a mean ($\pm$ SD) Sequential Organ Failure Assessment score of 7.9 ± 3.3 , Simplified Acute Physiology II score of 49.3 ± 16.5 , and a mortality rate of 11.9% in the intensive care unit and 16.4% in the hospital. We found a strong intraclass correlation (>0.85) for pH, partial pressure of carbon dioxide ($p\text{CO}_2$), bicarbonate, and base excess for ABG/pVBG, ABG/cVBG, and pVBG/cVBG comparisons. Agreement by the Bland-Altman method was found for pH (bias $\pm$ SD, 0.03 ± 0.04 , 0.03 ± 0.02 , and 0.00 ± 0.03) but not for $p\text{CO}_2$, partial pressure of oxygen, bicarbonate, base excess, and oxyhemoglobin saturation. In conclusion, adequate correlation and agreement between ABG/pVBG, ABG/cVBG, and pVBG/cVBG comparisons was found only for pH. The current level of evidence does not support the use of venous blood gas sampling in this setting.

KEYWORDS Blood gas; septic shock; severe sepsis

Sepsis, in association with multisystem organ failure and shock, may lead to respiratory failure, acute kidney injury, organ dysfunction, metabolic acidosis, and shock; thus, evaluation and management of acid-base status is frequently required.^{1,2} Traditionally, acid-base status is assessed with an arterial blood gas (ABG); however, venous blood samples are frequently taken for other reasons. This has prompted some to evaluate whether acid-base status could be assessed using a venous blood gas (VBG). The correlation and agreement between VBG and ABG has been described in prior studies evaluating diabetic ketoacidosis,^{3,4} chronic obstructive pulmonary disease,^{5–10} acute respiratory failure,^{11–13} trauma,¹⁴ and cardiac arrest^{15,16} and in studies with miscellaneous or unknown disorders.^{16–23} As a result of these previous investigations, our institution experienced a progressive increase in the utilization of VBGs. In an era of cost-appropriate care, the primary objective of this study was to evaluate the correlation and

agreement between ABG, peripheral venous blood gas (pVBG), and central venous blood gas (cVBG) in severe sepsis and septic shock.

METHODS

We conducted a prospective, observational cohort study to evaluate the correlation and agreement of arterial and venous blood gases in severe sepsis and septic shock. This study was conducted in accordance with the amended Declaration of Helsinki. The local institutional review board approved the protocol (Project ID 081821), and written informed consent was obtained from the patient or surrogate. Eligible patients admitted to the medical intensive care unit (MICU) aged 18 and older who fulfilled the definition of severe sepsis or septic shock² were screened for enrollment. The criteria for exclusion were cardiopulmonary arrest, pregnancy, prisoner or other ward of the state, and absence of a central venous catheter.

Corresponding author: Heath D. White, DO, MS, Clinical Assistant Professor, Division of Pulmonary, Critical Care, and Sleep Medicine, Department of Internal Medicine, Baylor Scott & White Health, 2401 S. 31st Street, Temple, TX 76508 (e-mail: Heath.White@BSWHHealth.org)

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ubmc.

Received January 8, 2018; Revised February 26, 2018; Accepted February 28, 2018.

Table 1. General characteristics of the 67 patients with severe sepsis or septic shock^a

Category	Variable	Descriptive statistics
Sex	Female	35 (52%)
Race	White	53 (79%)
	Black	6 (9%)
	Hispanic	4 (6%)
	Asian	4 (6%)
	Other	0 (0%)
Age	Mean	59 ± 17
	Range	19–90
Length of stay (days)	Hospital	17.2 ± 12.1
	MICU	11.7 ± 11.0
Comorbidities	Tobacco abuse	40 (60%)
	CAD/CHF	24 (36%)
	Diabetes mellitus	23 (34%)
	Peripheral vascular disease	14 (21%)
	Alcohol abuse	11 (16%)
	Immunocompromised	9 (13%)
	Chronic kidney disease	6 (9%)
	Hepatitis B or C	3 (4%)
	Cirrhosis	1 (1%)
	Intravenous drug abuse	1 (1%)

MICU indicates medical intensive care unit; CAD, coronary artery disease; CHF, congestive heart failure.

^aData are presented as No. (%) and mean ± SD unless indicated otherwise.

All patients admitted to the MICU were screened daily for inclusion/exclusion criteria. After informed consent and subject enrollment, the electronic medical record was reviewed for demographic data, comorbidities, severity of illness scores (Sequential Organ Failure Assessment [SOFA]²⁴ and Simplified Acute Physiology Score [SAPS II]²⁵) and assessment of sepsis origin.

Simultaneous blood gas samples including ABG, pVBG, and cVBG were collected within the first 48 hours of MICU admission. In an effort to enhance enrollment, samples were collected when the ABG was performed as part of routine medical care. The decision to order the ABG was based on clinical necessity by the subject's physician and independent of this research study.

All three samples were collected in standard blood gas syringes in a sequential manner within a time frame of no more than 15 minutes. Clinical personnel collected all blood gas samples using standard blood gas collection methods, and the samples were transported on ice to a central laboratory. The ABG was collected by either needle puncture or withdrawal from an arterial catheter. The cVBG was collected from any catheter that terminated at the cavoatrial junction. Catheter placement was confirmed by chest radiograph by study personnel. The pVBG was collected from the upper extremity, and a tourniquet could be left in place for no more than 1 minute. Blood gas samples were then analyzed using a blood gas analyzer (Radiometer model ABL 700 series,

Table 2. Blood gas descriptive statistics of the 67 patients with severe sepsis or septic shock

Variable	ABG (n = 67)	pVBG (n = 55)	cVBG (n = 65)
pH	7.35 ± 0.09	7.32 ± 0.10	7.31 ± 0.09
pCO ₂ (mm Hg)	39.9 ± 11.2	45.8 ± 12.9	45.2 ± 11.1
pO ₂ (mm Hg)	115 ± 61.0	62.0 ± 33.8	52.3 ± 20.1
Bicarbonate (mmol/L)	21.6 ± 6.4	23.0 ± 6.6	22.8 ± 6.6
Base excess (mmol/L)	−3.5 ± 6.7	−3.0 ± 6.9	−3.3 ± 6.8
Oxygen saturation	95.9 ± 4.0	81.7 ± 15.1	79.5 ± 9.8

ABG indicates arterial blood gas; pVBG, peripheral venous blood gas; cVBG, central venous blood gas; pCO₂, partial pressure of carbon dioxide; pO₂, partial pressure of oxygen.

Radiometer America, Inc., Westlake, OH) as part of routine processing. Data including pH, partial pressure of carbon dioxide (pCO₂), partial pressure of oxygen (pO₂), bicarbonate (HCO₃), base excess (BE), and oxyhemoglobin saturation (O₂ saturation) were recorded. Other data including the use of vasopressors and presence of mechanical ventilation were collected as well.

The primary outcome was pH measured from the ABG, pVBG, and cVBG. All variables of interest including demographic characteristics were summarized using descriptive statistics: mean (±SD) or median (range) for continuous variables and frequency (percent) for categorical variables. Intraclass correlation (ICC) analysis was performed for agreement between ABG, pVBG, and cVBG. Bland-Altman agreement analysis^{26,27} was performed for pH, pCO₂, pO₂, HCO₃, BE, and O₂ saturation between each pair of ABG, pVBG, and cVBG to evaluate agreement between the two blood gas types. HCO₃ and BE are recognized as calculated values from the blood gas analyzer. A *P* value < 0.05 indicated statistical significance. SAS 9.2 (SAS Institute Inc., Cary, NC) was used for statistical analysis.

The sample size calculation was performed to a standard error of the 95% limit of agreement between pH measured

Table 3. Intraclass correlation between arterial and venous blood gas measurements among 67 patients with severe sepsis or septic shock

Variable	ABG and pVBG (n = 55)	ABG and cVBG (n = 65)	pVBG and cVBG (n = 53)
pH	0.90 (<0.0001)	0.97 (<0.0001)	0.93 (<0.0001)
pCO ₂ (mm Hg)	0.86 (<0.0001)	0.93 (<0.0001)	0.88 (<0.0001)
pO ₂ (mm Hg)	0.34 (0.01)	0.18 (0.15)	0.32 (0.02)
Bicarbonate (mmol/L)	0.95 (<0.0001)	0.96 (<0.0001)	0.97 (<0.0001)
Base excess (mmol/L)	0.97 (<0.0001)	0.97 (<0.0001)	0.98 (<0.0001)
Oxygen saturation	0.01 (0.94)	0.11 (0.38)	0.37 (0.01)

ABG indicates arterial blood gas; pVBG, peripheral venous blood gas; cVBG, central venous blood gas; pCO₂, partial pressure of carbon dioxide; pO₂, partial pressure of oxygen.

Table 4. Bland-Altman analysis for comparisons of arterial and venous blood gas measurements among 67 patients with severe sepsis or septic shock^a

Variable	Comparator 1	Comparator 2	Bias	95% LOA
ABG vs pVBG (<i>n</i> = 55)				
pH	7.35 ± 0.09	7.32 ± 0.10	0.03 ± 0.04	−0.05, 0.11
pCO ₂ (mm Hg)	40.7 ± 11.0	45.8 ± 12.9	−5.1 ± 6.1	−16.9, 6.76
pO ₂ (mm Hg)	116 ± 63.5	62.0 ± 33.8	54.3 ± 57.2	−57.8, 166.4
HCO ₃ (mmol/L)	22.1 ± 6.4	23.0 ± 6.6	−0.9 ± 1.9	−4.62, 2.77
BE (mmol/L)	−3.1 ± 6.6	−3.0 ± 6.9	−0.2 ± 1.5	−3.10, 2.77
O ₂ saturation (%)	95.8 ± 4.0	81.7 ± 15.1	14.1 ± 14.9	−15.0, 43.2
ABG vs cVBG (<i>n</i> = 65)				
pH	7.34 ± 0.09	7.31 ± 0.09	0.03 ± 0.02	−0.01, 0.07
pCO ₂ (mm Hg)	39.9 ± 11.2	45.2 ± 11.1	−5.3 ± 4.1	−13.4, 2.78
pO ₂ (mm Hg)	116 ± 61.3	52.3 ± 20.1	64.6 ± 58.5	−50.1, 179.2
HCO ₃ (mmol/L)	21.5 ± 6.5	22.8 ± 6.6	−1.31 ± 1.8	−4.91, 2.29
BE (mmol/L)	−3.7 ± 6.7	−3.3 ± 6.8	−0.4 ± 1.6	−3.59, 2.83
O ₂ saturation (%)	96.0 ± 4.0	79.5 ± 9.8	16.5 ± 9.9	−2.96, 35.9
pVBG vs cVBG (<i>n</i> = 53)				
pH	7.32 ± 0.10	7.31 ± 0.08	0.00 ± 0.03	−0.06, 0.07
pCO ₂ (mm Hg)	45.6 ± 12.9	46.0 ± 11.4	−0.4 ± 5.6	−11.4, 10.5
pO ₂ (mm Hg)	63.0 ± 34.1	52.7 ± 20.9	10.3 ± 31.3	−51.0, 71.6
HCO ₃ (mmol/L)	22.9 ± 6.7	23.3 ± 6.7	−0.4 ± 1.6	−3.57, 2.78
BE (mmol/L)	−3.1 ± 6.9	−2.8 ± 6.9	−0.3 ± 1.3	−2.82, 2.25
O ₂ saturation (%)	82.3 ± 15.0	79.6 ± 10.2	2.8 ± 13.7	−24.2, 29.7

LOA indicates limit of agreement; ABG, arterial blood gas; pVBG, peripheral venous blood gas; pCO₂, partial pressure of carbon dioxide; pO₂, partial pressure of oxygen; HCO₃, bicarbonate; BE, base excess; O₂ saturation, oxyhemoglobin saturation; cVBG, central venous blood gas.

^aData are presented as mean ± SD.

from each pair of three blood gases (ABG vs pVBG, ABG vs cVBG, and pVBG vs cVBG) to detect an ICC coefficient of 0.8 between pH measured from three blood gases. A sample size of 80 was required to achieve a 95% confidence interval of each limit of agreement between pH measured from each pair of three blood gases, falling within ±0.38 standard deviation of difference between pH measured from each pair of the three blood gases. This sample size was developed to achieve 81% power to detect an ICC of 0.8 under the alternative hypothesis when the ICC under the null hypothesis is 0.7 using an F-test with a significance level of 0.05.

RESULTS

During the study period, 1796 admissions to the MICU were screened for severe sepsis and septic shock. A total of 273 subjects met the inclusion/exclusion criteria, and 67 subjects (24.5%) were enrolled in the study. The remaining subjects were excluded for the following reasons: absence of central venous catheter (*n* = 53), prisoner or ward of the state (*n* = 8), cardiac arrest (*n* = 11), unable to consent in the study enrollment time period (*n* = 46), ABG not obtained in routine medical care (*n* = 27), and declined participation/unable to consent (*n* = 61).

Complete data were collected for 53 subjects (unable to collect a pVBG in 12 subjects and a cVBG in two subjects). Data analysis was performed on the 67-subject and 53-subject (analysis not shown) data sets separately. No difference in the primary results was found, and the data described hereafter represent the 67-subject group.

The general characteristics of the subjects are shown in *Table 1*. The most common comorbid conditions were tobacco abuse (59.7%), heart disease (35.8%), and diabetes mellitus (34.3%). Underlying lung disease was present in 31.3%, with chronic obstructive pulmonary disease and asthma accounting for all cases. Thirteen subjects had a current or prior history of malignancy, of which the most commonly reported type was breast cancer (69.2%).

Severity of illness scores revealed a mean (±SD) SOFA of 7.9 ± 3.3 and SAPS II of 49.3 ± 16.5. The mortality rates in the MICU and hospital were 11.9% and 16.4%, respectively. Vasopressors were utilized in 46.3% and mechanical ventilation in 85.1% of the subjects. Lactic acid and HCO₃ levels, when collected in the 24 hours prior to blood gas collection, were 2.5 ± 2.3 mmol/L and 21.7 ± 6.6 mEq/L, respectively.

Twenty different etiologies of severe sepsis and septic shock were identified. The most common were community-acquired

Figure 1. Bland-Altman plots of (a) ABG vs pVBG pH comparison; (b) ABG vs cVBG pH comparison; and (c) pVBG vs cVBG pH comparison.

pneumonia, 23 (34.3%); health care-associated pneumonia, 17 (25.4%); bacteremia, 10 (14.9%); and urinary tract infections, 5 (7.5%).

Table 2 provides results for the ABG, pVBG, and cVBG tests, including pH, $p\text{CO}_2$, $p\text{O}_2$, HCO_3 , BE, and O_2 saturation. ICC analysis was performed for each pair of blood gases (ABG/pVBG, ABG/cVBG, and pVBG/cVBG). A significant correlation, in each of the three pairs, was found for pH, $p\text{CO}_2$, HCO_3 , and BE, with an ICC > 0.85 (Table 3).

The Bland-Altman method, calculating the mean difference between two methods of measurement, was utilized for each pair of blood gases (Table 4, Figure 1). Analysis of agreement was based on the bias, 95% limits of agreement (LOAs), and review of individual Bland-Altman plots. Comparison revealed adequate agreement in all three comparisons, ABG/pVBG, ABG/cVBG, and pVBG/cVBG, for pH (bias $\pm$ SD, 0.03 ± 0.04 , 0.03 ± 0.02 , and 0.00 ± 0.03 , respectively). Agreement was found to be poor for $p\text{CO}_2$, $p\text{O}_2$, HCO_3 , BE, and O_2 saturation.

Subgroup analysis was performed for ICC to assess for differences in the use of vasopressors, mechanical ventilation,

hospital mortality, and severity of illness scores (SOFA and SAPS II). No difference could be seen in the ICC for these subgroups, with the exception of the use of mechanical ventilation. In this subgroup, analysis could not be reliably interpreted secondary to unequal group numbers, with 85.1% of the subjects requiring mechanical ventilation (data not shown).

DISCUSSION

The substitution of venous for arterial sampling during blood gas analysis has been evaluated with cardiac arrest, chronic obstructive pulmonary disease, diabetic ketoacidosis, and miscellaneous forms of acute respiratory failure. The utility of this laboratory information is still debated in the medical literature. Based on extrapolation of the current literature, in the last 10 years at our institution there has been an increase in the utilization of VBGs by 1.9- and 9.5-fold in the medical/surgical floors and emergency department, respectively (Figure 2). Although a blood gas analysis may be relatively inexpensive, an exponential increase in utilization coupled with unproven scientific validity and the need for cost-conscious medical practice should lead medical providers to question the usage of this laboratory tool. Additionally, there is a near absence of literature assessing whether treatment and outcomes are altered with the limited information (i.e., pH) that can be reliably obtained from a VBG.

Figure 2. (a) ABG and (b) VBG utilization and trend over time by location within our institution.

With knowledge of this debate and knowing the frequency with which this substitution has been adopted over time, we evaluated the substitution of VBG for ABG in severe sepsis and septic shock, a disease process that to our knowledge has not been specifically studied. In subjects with severe sepsis and

septic shock, we found a strong ICC for pH, pCO₂, HCO₃, and BE (ICC > 0.85) for the three comparison modalities tested, and strong agreement by Bland-Altman method was found for pH (bias ± SD, 0.03 ± 0.04, 0.03 ± 0.02, and 0.00 ± 0.03) for each of the three comparison modalities. The

Table 5. Literature review of blood gas comparison

Study	Year	Subjects	Etiology	Bias	SD	95% LOA	Article interpretation
pH							
McKeever et al ¹⁰	2016	234	AECOPD	0.03		−0.05 0.11	+
Kelly and Klim ¹²	2013	53	ARF and NIV	0.04		−0.02 0.11	+
Koul et al ²³	2011	100	Miscellaneous	−0.030	0.030	−0.088 0.028	+
Treger et al ¹⁷	2010	40	Miscellaneous, sepsis 72.5%	0.027	0.027	−0.028 0.081	+
Toftegaard et al ⁸	2008	73	COPD, shock, nonshock	0.026	0.023	−0.020 0.071	+
Malatesha et al ¹⁹	2007	95	Miscellaneous	−0.015		−0.1 0.13	+
Middleton et al ²¹	2006	110	Unknown, ICU patients	−0.03		−0.07 0.01	+
Malinoski et al ¹⁴	2005	25	ICU trauma on MV	−0.032	0.026	−0.09 0.03	−
Ma et al ³	2003	200	Diabetic ketoacidosis	−0.015		0.021 −0.009	+
Rang et al ¹⁸	2002	214	Miscellaneous	0.036	0.08		−
Kelly et al ¹³	2002	196	ARF	−0.034		−0.10 0.04	+
Kelly et al ¹¹	2001	246	ARF and metabolic disorder	−0.04		−0.11 0.04	+
Bradenburg and Dire ⁴	1998	38	Diabetic ketoacidosis	0.03			+
Partial pressure of carbon dioxide (mm Hg)							
McKeever et al ¹⁰	2016	234	AECOPD	−5.63		−21.8 10.6	−
Kelly and Klim ¹²	2013	53	ARF and NIV	−8.02		−22.63 6.58	−
McCanny et al ⁶	2011	89	AECOPD	8.6		−7.84 25.05	−
Koul et al ²³	2011	100	Miscellaneous	−4.05	4.48	−12.8 4.7	+
Treger et al ¹⁷	2010	40	Miscellaneous, sepsis 72.5%	−3.8	4.3	−12.3 4.8	+
Toftegaard et al ⁸	2008	73	COPD, shock, nonshock	−4.47	4.27	−12.81 3.86	−
Malatesha et al ¹⁹	2007	95	Miscellaneous	3.0		−7.6 6.8	+
Malinoski et al ¹⁴	2005	25	ICU trauma on MV	−4.36	3.34	−2.2 10.9	−
Kelly et al ⁵	2005	107	AECOPD	6		−14 26	−
Rang et al ¹⁸	2002	214	Miscellaneous	6.0	13.9		−
Kelly et al ¹³	2002	196	ARF	5.8		−8.8 20.5	−
Bicarbonate (mmol/L)							
McKeever et al ¹⁰	2016	234	AECOPD	−0.04		−2.90 2.82	+
Koul et al ²³	2011	100	Miscellaneous	0.86	2.15	−3.35 5.09	+
Treger et al ¹⁷	2010	40	Miscellaneous, sepsis 72.5%	−0.80	1.58	−4.0 2.4	+
Malatesha et al ¹⁹	2007	95	Miscellaneous	0.74		−5.8 4.3	+
Middleton et al ²¹	2006	110	Unknown, ICU patients	0.52		−1.81 2.85	+
Rang et al ¹⁸	2002	214	Miscellaneous	1.5	3.5		−
Base excess (mmol/L)							
Middleton et al ²¹	2006	110	Unknown, ICU patients	0.19		−1.86 2.24	+
Malinoski et al ¹⁴	2005	25	ICU trauma on MV	0.18	1.03	−2.2 1.8	−

LOA indicates limit of agreement; AECOPD, acute exacerbation of COPD; ARF, acute respiratory failure; NIV, noninvasive ventilation; COPD, chronic obstructive pulmonary disease; ICU, intensive care unit; MV, mechanical ventilation.

substitution of VBG for ABG was not supported for pCO₂, pO₂, HCO₃, BE, and O₂ saturation.

Table 5 summarizes the studies that include correlation and agreement analyses, specifically Bland-Altman analysis. These studies, which are heterogeneously displayed, by and large report adequate correlation and agreement for pH; the sole negative paper makes an argument that the LOAs (−0.09 to 0.03) do not allow for substitution, although these LOAs are larger than most of the other studies. Most studies reporting pCO₂ have a negative interpretation with variable bias and LOA. Looking at this literature as a heterogeneous whole and recognizing that Bland-Altman analysis requires a clinical interpretation of significance, the findings are largely variable with variable LOA and variable interpretation of significance individually. These findings as a whole would not support the substitution of venous for arterial sampling. This conclusion is further supported by a recent systematic review and meta-analysis by Byrne et al.²⁸

The comparison of venous and arterial blood gases in sepsis has not been specifically studied. In the only study that indirectly addresses this population, Treger and colleagues¹⁷ evaluated agreement between cVBG and ABG in a generalized MICU population, which included sepsis as the primary diagnosis in 72.5%. The remaining etiologies consisted of 11 different diagnoses. Subgroup analysis of the sepsis group was not performed.

Though there are no specific recommendations regarding the assessment of acid-base status in the management of sepsis, the pathophysiology of sepsis may impart the need to make such assessment periodically. Acidosis is a frequent consequence of sepsis, particularly with the development of lactic acidosis as well as respiratory or renal dysfunction. One could argue for the assessment of acid-base status as a routine component of the evaluation and management of sepsis. Our study and the previous literature¹⁷ would not support the use of VBGs in the treatment of sepsis, because patients with sepsis frequently have mixed acid-base disorders. Only being able to reliably use the pH from a VBG would realistically provide no clinically meaningful information in sepsis.

This study has several limitations that should be considered during interpretation of the results. The sample size of this study was calculated based on the pH with an expected power of 81% if all subjects were enrolled with complete data. Although the sample size was not achieved, correlation and agreement for pH were found. The findings for pCO₂, pO₂, HCO₃, BE, and O₂ saturation were not found to have correlation and agreement; it is unknown whether pCO₂ has correlation and agreement in the absence of adequate sample size and a power analysis calculated for this study variable. The protocol design allowed for collection of blood gas samples within a 48-hour window of admission to the MICU. During this window, the source of sepsis had been treated with antibiotics, volume resuscitation, and other modalities that may have altered or corrected the initial acid-base state. Although this probably had no effect on the correlation and agreement between blood gases, it does limit the degree of extrapolation for severe acidosis, because the initial acid-base disorder may have

been partially or completely corrected by the time of collection. Despite this assumption, acidosis was still a predominant finding in 46.3% of the subjects.

In conclusion, adequate correlation and agreement between ABG/pVBG, ABG/cVBG, and pVBG/cVBG comparisons were found for pH but not for other variables included in the blood gas analysis in severe sepsis and septic shock. The findings of our study and previous literature would suggest that VBG should not be used for the interpretation of acid-base state in the setting of severe sepsis and septic shock and should only be used in other disorders under specific circumstances. This substitution should be used with recognition of the significant limitations present.

FUNDING

Funding for this study was provided through the Scott & White Research Grant Program. Preliminary findings of this study were presented as a poster presentation at Chest in Atlanta, Georgia, on October 24, 2012.

ORCID

Heath D. White <http://orcid.org/0000-0003-1065-3681>

Alfredo Vazquez-Sandoval <http://orcid.org/0000-0002-0979-7808>

Pedro F. Quiroga <http://orcid.org/0000-0003-0658-8290>

Shirley F. Jones <http://orcid.org/0000-0001-8637-0317>

Alejandro C. Arroliga <http://orcid.org/0000-0002-7245-2159>

1. Angus DC, Linde-Zwirble WT, Lidicker J, et al. Epidemiology of severe sepsis in the United States: analysis of incidence, outcome, and associated costs of care. *Crit Care Med*. 2001;29:1303–1310. doi:10.1097/00003246-200107000-00002.
2. Bone RC, Balk RA, Cerra FB, et al. Definitions for sepsis and organ failure and guidelines for the use of innovative therapies in sepsis. *Chest*. 1992;101:1644–1655. doi:10.1378/chest.101.6.1644.
3. Ma OJ, Rush MD, Godfrey MM, Gaddis G. Arterial blood gas results rarely influence emergency physician management of patients with suspected diabetic ketoacidosis. *Acad Emerg Med*. 2003;10:836–841. doi:10.1111/j.1553-2712.2003.tb00625.x.
4. Brandenburg MA, Dire DJ. Comparison of arterial and venous blood gas values in the initial emergency department evaluation of patients with diabetic ketoacidosis. *Ann Emerg Med*. 1998;31:459–465. doi:10.1016/S0196-0644(98)70254-9.
5. Kelly AM, Kerr D, Middleton P. Validation of venous pCO₂ to screen for arterial hypercarbia in patients with chronic obstructive airways disease. *J Emerg Med*. 2005;28:377–379. doi:10.1016/j.jemermed.2004.10.017.
6. McCann P, Bennett K, Staunton P, McMahon G. Venous vs arterial blood gases in the assessment of patients presenting with an exacerbation of chronic obstructive pulmonary disease. *Am J Emerg Med*. 2012;30:896–900. doi:10.1016/j.ajem.2011.06.011.
7. Ak A, Ogun CO, Bayir A, Kayis SA, Koylu R. Prediction of arterial blood gas values from venous blood gas values in patients with acute exacerbation of chronic obstructive pulmonary disease. *Toboku J Exp Med*. 2006;210:285–290. doi:10.1620/tjem.210.285.
8. Toftgaard M, Rees SE, Andreassen S. Correlation between acid-base parameters measured in arterial blood and venous blood sampled peripherally, from vena cava superior, and from the pulmonary artery. *Eur J Emerg Med*. 2008;15:86–91. doi:10.1097/MEJ.0b013e3282e6f5c5.
9. Razi E, Moosavi GA. Comparison of arterial and venous blood gases analysis in patients with exacerbation of chronic obstructive pulmonary disease. *Saudi Med J*. 2007;28:862–865.
10. McKeever TM, Hearson G, Housley G, et al. Using venous blood gas analysis in the assessment of COPD exacerbations: a prospective cohort study. *Thorax*. 2016;71:210–215. doi:10.1136/thoraxjnl-2015-207573.

11. Kelly AM, McAlpine R, Kyle E. Venous pH can safely replace arterial pH in the initial evaluation of patients in the emergency department. *Emerg Med J*. 2001;18:340–342. doi:10.1136/emj.18.5.340.
12. Kelly AM, Klim S. Agreement between arterial and venous pH and pCO₂ in patients undergoing non-invasive ventilation in the emergency department. *Emerg Med Australas*. 2013;25:203–206. doi:10.1111/1742-6723.12066.
13. Kelly AM, Kyle E, McAlpine R. Venous pCO₂ and pH can be used to screen for significant hypercarbia in emergency patients with acute respiratory disease. *J Emerg Med*. 2002;22:15–19. doi:10.1016/S0736-4679(01)00431-0.
14. Malinoski DJ, Todd SR, Slone S, Mullins RJ, Schreiber MA. Correlation of central venous and arterial blood gas measurements in mechanically ventilated trauma patients. *Arch Surg*. 2005;140:1122–1125. doi:10.1001/archsurg.140.11.1122.
15. Steedman DJ, Robertson CE. Acid base changes in arterial and central venous blood during cardiopulmonary resuscitation. *Arch Emerg Med*. 1992;9:169–176. doi:10.1136/emj.9.2.169.
16. Adrogué HJ, Rashad MN, Gorin AB, Yacoub J, Madias NE. Assessing acid-base status in circulatory failure. Differences between arterial and central venous blood. *N Engl J Med*. 1989;320:1312–1316. doi:10.1056/NEJM198905183202004.
17. Treger R, Pirouz S, Kamangar N, Corry D. Agreement between central venous and arterial blood gas measurements in the intensive care unit. *Clin J Am Soc Nephrol*. 2010;5:390–394. doi:10.2215/CJN.00330109.
18. Rang LC, Murray HE, Wells GA, Macgougan CK. Can peripheral venous blood gases replace arterial blood gases in emergency department patients? *CJEM*. 2002;4:7–15. doi:10.1017/S1481803500006011.
19. Malatesha G, Singh NK, Bharija A, Rehani B, Goel A. Comparison of arterial and venous pH, bicarbonate, pCO₂ and pO₂ in initial emergency department assessment. *Emerg Med J*. 2007;24:569–571. doi:10.1136/emj.2007.046979.
20. Phillips B, Peretz DI. A comparison of central venous and arterial blood gas values in the critically ill. *Ann Intern Med*. 1969;70:745–749. doi:10.7326/0003-4819-70-4-745.
21. Middleton P, Kelly AM, Brown J, Robertson M. Agreement between arterial and central venous values for pH, bicarbonate, base excess, and lactate. *Emerg Med J*. 2006;23:622–624. doi:10.1136/emj.2006.035915.
22. Sutton RN, Wilson RF, Walt AJ. Differences in acid–base levels and oxygen-saturation between central venous and arterial blood. *Lancet*. 1967;2:748–751. doi:10.1016/S0140-6736(67)91947-2.
23. Koul PA, Khan UH, Wani AA, et al. Comparison and agreement between venous and arterial gas analysis in cardiopulmonary patients in Kashmir valley of the Indian subcontinent. *Ann Thorac Med*. 2011;6:33–37. doi:10.4103/1817-1737.74274.
24. Vincent JL, de Mendonça A, Cantraine F, et al. Use of the SOFA score to assess the incidence of organ dysfunction/failure in intensive care units: results of a multicenter, prospective study. Working group on “sepsis-related problems” of the European Society of Intensive Care Medicine. *Crit Care Med*. 1998;26:1793–1800. doi:10.1097/00003246-199811000-00016.
25. Le Gall JR, Lemeshow S, Saulnier F. A new Simplified Acute Physiology Score (SAPS II) based on a European/North American multicenter study. *JAMA*. 1993;270:2957–2963. doi:10.1001/jama.1993.03510240069035.
26. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1:307–310. doi:10.1016/S0140-6736(86)90837-8.
27. Bland JM, Altman DG. Comparing methods of measurement: why plotting difference against standard method is misleading. *Lancet*. 1995;346:1085–1087. doi:10.1016/S0140-6736(95)91748-9.
28. Byrne AL, Bennett M, Chatterji R, Symons R, Pace NL, Thomas PS. Peripheral venous and arterial blood gas analysis in adults: are they comparable? A systematic review and meta-analysis. *Respirology*. 2014;19:168–175. doi:10.1111/resp.12225.