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ACCURACY OF ACID-BASE DIAGNOSES USING THE CENTRAL VENOUS BLOOD GAS IN THE MEDICAL INTENSIVE CARE UNIT

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Abstract

Background—Acid-base disturbances are frequent in critically ill patients. Arterial blood gas (ABG) is the gold standard in the diagnosis of these disturbances but it is invasive with potential hazards. For patients with a central venous catheter, venous blood gas (VBG) sampling may be an alternative, less-invasive diagnostic tool. However, the accuracy of a central VBG-based acid-base disorder diagnosis compared to an ABG is unknown. The primary objective of this study was to assess the accuracy of a central VBG-based acid-base disorder diagnosis compared to the “gold standard” ABG, in critically ill patients.

Methods—This was a study of adult patients in a medical intensive care unit (MICU) that had simultaneously drawn ABG and central VBG samples. Expert acid-base diagnosticians, all nephrologists, diagnosed the acid-base disorder(s) in each blood gas sample. The central VBG diagnostic accuracy was assessed with percent agreement, sensitivity and specificity compared to the ABG-based diagnosis.

Results—The study involved 23 participants. Overall, the central VBG had 100% sensitivity for metabolic acidosis, metabolic alkalosis, and respiratory acidosis, and lower sensitivity (71%) for respiratory alkalosis, and high percent agreement, ranging from 75–94%. VBG-based diagnoses in vasopressor-dependent patients (n=13, 56.5%) performed similarly to the entire sample.

Conclusions—In critically ill adult patients, central VBG may be used to detect and diagnose acid-base disturbances with reasonable diagnostic accuracy, even in shock states, compared to the ABG. This study supports the use of central VBG for diagnosis of acid-base disturbances in critically ill patients.

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Keywords

acid-base; medical intensive care unit; acidosis; alkalosis; venous blood gas; arterial blood gas

Introduction

Acid-base disturbances are frequently encountered in critically ill patients. Arterial blood gas (ABG) samples are the current gold standard for the diagnosis and clinical management of these acid-base disturbances. Venous blood gas (VBG) has been proposed as an alternative to ABG sampling due to safety concerns related to the need to perform an arterial puncture or catheterization. Several studies have shown that there is a good correlation between individual VBG and ABG test result components (e.g., pH, partial pressure of carbon dioxide (pCO₂) and calculated bicarbonate [HCO₃]).[1–4] However, importantly, these studies have not assessed the use of VBG samples in the detection and diagnosis of acid-base disorder in critically ill adults.[5–7]

The primary objective of this study was to assess the accuracy of detecting and diagnosing acid-base disorders using a central VBG sample to determine a clinical diagnosis compared to an ABG-based diagnosis from simultaneously drawn ABG sample in critically ill adult patients in the medical ICU (MICU).

Methods

Participants

This was a cross-sectional multi-center study of adult patients admitted to a MICU over a 2-month period at two university-based, tertiary referral urban hospitals. A convenience sampling of patients older than 18 years with pre-existing indwelling arterial and central venous catheters and a clinical need for acid-base and chemistry determination were eligible for this study. The study protocol was approved by the Institutional Review Board at the University of Pennsylvania and is in accordance with the Declaration of Helsinki. Informed consent was provided by study participants.

Specimen Collection

When a blood gas sample was deemed necessary for routine care, the nurse caring for each eligible participant drew a single sample of arterial blood (0.5–1 milliliter (mL)) from an indwelling arterial catheter and a sample of venous blood from an indwelling central venous catheter (0.5–1 mL). The samples were obtained within 2 minutes of each other. The blood gas samples were analyzed using the critical care lab blood gas analyzers, Instrument Laboratory GEM 4000 and Nova Critical Care Xpress. For each sample, the pH, pCO₂, and HCO₃ were recorded. The results of ABG and VBG samples, along with laboratory data, other clinical data including primary diagnoses, presence of current hypotension (defined as systolic blood pressure less than 90 millimeters of mercury (mmHg)), current vasopressor or inotrope use, current acute kidney injury (defined as absolute increase in serum creatinine 0.3 mg/dL or more from baseline creatinine level at any time during the hospitalization prior to the blood gas sample draw), and the presence of mechanical ventilation were recorded.

Blood Gas Interpretation

Three nephrologists experienced in blood gas interpretation and diagnosis (RC, SG, DN) interpreted the ABG sample results along with the most recent basic metabolic panel to determine the “gold standard” diagnosis for each sample. Subsequently, at a later date, each expert interpreted the paired central VBG sample with the basic metabolic panel without prior knowledge of the paired ABG sample and its corresponding diagnosis. All blood gas samples were classified as showing: no disorder, metabolic acidosis, metabolic alkalosis, respiratory acidosis, respiratory alkalosis, or as a mixed disorder. The final diagnosis of each blood gas sample was determined if all three of the expert interpretations agreed; in the case of any disagreement, a fourth expert (JB) who was aware of the other proposed diagnoses, performed an arbitration to determine the final diagnosis, using clinical judgment and commonly used formulae.[8, 9] Each separate acid-base disorder identified using the ABG comprised the sample size of acid-base disorders, including those that were part of a mixed acid-base disorder.

Statistical Methods

We describe the study population using mean, standard deviation, or median and interquartile range for continuous variables and frequency and proportion for categorical variables.

Inter-rater reliability of the expert diagnoses was assessed with kappa statistics.[10] The accuracy of the central VBG diagnoses compared to the ABG as the “gold standard” was assessed by percent agreement, as well as sensitivity and specificity. Agreement of the central VBG and ABG diagnoses was defined as: 1) *complete agreement* – the VBG-based diagnosis agreed completely with the ABG-based diagnosis (assigned score of one), 2) *partial agreement* – pertains to a mixed acid base disorder - in which the VBG-based diagnosis correctly identified at least one acid-base disorder but did not identify another acid-base disorder diagnosed by the ABG (assigned score of 0.5), or 3) *no agreement* – the VBG-based diagnosis did not identify any disorder(s) diagnosed by ABG (assigned score of zero). The percent agreement was calculated as the summation of the agreement scores divided by the sample size, multiplied by 100. Percent agreement was also calculated for the subgroup of participants deemed to have shock, as indicated by current vasopressor use and/or current hypotension.

To determine the sensitivity and specificity, the central VBG-based diagnosis was considered the diagnostic test and the ABG-based diagnosis was considered the gold standard. Sensitivity of the central VBG-based diagnoses was calculated as the number of true positives (correctly diagnosed presence of disorder) divided by the number of true positives and false negatives (failure to detect presence of disorder). Specificity was calculated as the number of true negatives (correctly identified absence of disorder) divided by the number of true negatives and false positives (incorrect identification of disorder). Each acid-base disturbance was counted, even if it comprised one component of a mixed acid-base disorder.

Results

The study involved 23 patients with paired ABG and central VBG samples, all of which were included in the analyses. Table 1 shows the patient characteristics. The patient population consisted of slightly more women (61%) than men, with a mean age $\pm$ SD of 62.5 ± 18.8 years. The most common primary diagnoses were respiratory-related (45.5%) and sepsis (40.9%). The vast majority of patients were intubated (82.6%), and about half (52.2%) were on vasopressors. The range of ABG and central VBG values along with median and SD are reported in Table 2.

The diagnostic accuracy of the central VBG-based diagnoses was high, with the overall percent agreement between the central VBG and ABG diagnoses at 69.6%. The central VBG-based diagnostic sensitivity was 100% for metabolic acidosis, metabolic alkalosis, and respiratory acidosis (Table 3). Only respiratory alkalosis had a lower diagnostic sensitivity of 71%. The high diagnostic sensitivity for the three major disturbances corresponds to a high overall percent agreement for each disorder, ranging from 75–94%, with a lower agreement of 57% for respiratory alkalosis (Table 4). For each alkalosis (metabolic and respiratory), the central VBG-based diagnosis had 100% specificity, while for each acidosis, the specificity was approximately 60%. In the subgroup analysis of participants in shock ($n=13$, 56.5%), the central VBG-based diagnosis performed very similarly to the entire sample (Table 3 and 4), with acidotic disorders having the highest percent agreement, and alkalotic disorders with the lowest.

The reliability between the experts was substantial for ABG (κ 0.76), and fair for the central VBG diagnoses (κ 0.33). Of the 23 ABG samples, there were two with no acid-base disturbance identified. Among the remaining 21 samples with acid-base disturbances identified, there were 13 with a single acid-base disturbance, consisting of metabolic acidosis (4), metabolic alkalosis (2), respiratory acidosis (2), and respiratory alkalosis (5). There were eight samples with mixed acid-base disturbances identified, consisting of metabolic acidosis with respiratory alkalosis (2), and metabolic acidosis with respiratory acidosis (6). Please see supplementary data for further information.

DISCUSSION

To our knowledge, this is among the first studies to assess the diagnostic accuracy of a central VBG for detection and diagnosis of acid-base disorders compared to use of an ABG in critically ill adult MICU patients. Our findings show that there is significant agreement between the central VBG- and ABG-based diagnoses, as measured by percentage agreement, sensitivity, and specificity for the major acid-base disturbances. Similarly, substantial agreement was also found in patients with clinical states of shock.

Most prior studies comparing ABG and VBG results in adults have focused on correlations of the individual laboratory component values (e.g., pH, $p\text{CO}_2$, and bicarbonate) rather than on the accuracy of detection and diagnosis of acid-base disorder.[1–4] Specifically in a pathologically diverse ICU population, a study by Treger et al. found that the ABG and central VBG values of pH, PCO_2 and bicarbonate were highly correlated, but the accuracy

of the central VBG-based diagnosis for acid-base disturbances was not assessed.[6] Walkey, et al. found high levels of diagnostic agreement for normal acid-base status using adjusted central VBG and ABG samples, but the study was limited by a small number of critically ill patients and the few abnormal blood gas samples.[11] There has been one study published to date focused on the reliability of the central VBG-based diagnosis compared to ABG-based diagnosis for acid-base disturbances in the critically ill, but this was limited to children.[12] The current study builds upon these prior studies to assess the accuracy of central VBG-based diagnoses compared to ABG diagnoses using clinical judgment for acid-base disturbances in critically ill adults.

This study demonstrates that a central VBG-based diagnosis has excellent sensitivity for acid-base disturbances, with 100% sensitivity for metabolic acidosis, metabolic alkalosis, respiratory acidosis, with somewhat lower but still reasonably high sensitivity for respiratory alkalosis at 71%. Percent complete agreement among the acidotic disorders was also high, with low partial agreement, and complete lack of no agreement, which translates into an excellent ability of the central VBG to diagnosis the presence of an ABG-detected acidosis. Of note, the central VBG-based diagnosis of an acidosis should be interpreted in light of its lower specificity (around 60%), primarily due to the incorrect interpretation of the presence of a respiratory acidosis, which is likely due to the higher pCO₂ levels found in the central VBG samples compared to ABG samples. This issue is highlighted in the higher levels of partial agreement found among the alkalotic disorders (29% and 50% for respiratory and metabolic, respectively), which was due to the detection and diagnosis of a respiratory acidosis by central VBG, which was not diagnosed by the ABG. Although not enforced in this study, application of an adjustment factor for these known differences in pCO₂ between sampling sites could potentially limit this error.[11] Another potential reason for a lower specificity of a central VBG diagnosis of an acidosis is the inappropriate detection of a metabolic acidosis in the presence of a respiratory alkalosis, which could possibly reflect that clinically a respiratory alkalosis can frequently be mixed with metabolic acidosis and clinical information and serial blood gas measurements are needed to arrive at a proper diagnosis. Furthermore, in this study, the presence of a mixed acid-base disorder did not seem to have a large effect on the clinical interpretation, as all eight samples with mixed disturbances (six with metabolic acidosis and respiratory acidosis and two with metabolic acidosis and respiratory alkalosis) correctly identified both disorders present. However, we did not assess mixed acid-base disturbances with metabolic alkalosis or samples with more than two disturbances, thus limiting the current knowledge of the central VBG's ability to identify the acid-base disorders in these circumstances.

To address the concern of a central VBG's ability to identify the correct acid-base disorder that was defined by an ABG, we examined the level of central VBG-based sensitivity. In our study, respiratory alkalosis was the only main acid-base disturbance to be missed by the central VBG, as evidenced by a sensitivity lower than 100%, but still relatively high at 71%. The other missed diagnosis by the central VBG was the lack of an acid-base disorder, which was detected by the ABG. However, identifying the lack of an acid-base disturbance does not address the ability of a central VBG to detect the presence of an acid-base disturbance, which is the primary concern of this study. To exclude the presence of an acid-base disorder, an ABG would likely be needed, especially to rule out respiratory acidosis.

Overall, since the majority of acid-base disturbances diagnosed with an ABG sample were also correctly diagnosed using the simultaneous central VBG sample, and the number of acid-base disturbances missed by the central VBG was quite low, central VBG sampling for diagnosing acid-base disorders could potentially prevent the need for arterial blood sampling in critically ill adult patients. Utilizing central VBG-based diagnosis for acid-base diagnoses would reduce the risk of potential hazards of bleeding, vasospasm, or thrombosis.

Strengths of this study are the novel approach to assess the diagnostic accuracy of central VBG-based diagnoses by utilizing multiple acid-base experts and use of simultaneous ABG and central VBG samples to assess the agreement between the paired central VBG and ABG-based diagnoses. The study does have limitations. First, the sample size was small, with one paired arterial and central venous sample for each patient. However, despite the small sample size, we are reassured by the consistency of the blood gas measurements with existing literature, in that the blood gas values in this study were very similar to that obtained in Treger, et al., which comprised of a much larger sample with 190 paired blood gas samples in critically ill adults. Second, the patient selection did not involve random sampling, and could lead to biased estimates of the sensitivity and specificity if the sampled participants were not representative of the typical MICU population. However, this is unlikely to have resulted in systematic bias since we believe the demographics and clinical characteristics of our sample reflect the population of a typical MICU. In conclusion, this study demonstrates that a central VBG sample can be used to accurately detect and correctly diagnose acid-base disturbances in critically ill adult MICU patients.

Conclusions

In critically ill adult patients, central VBG may be used to detect and diagnose acid-base disturbances with reasonable diagnostic accuracy, even in shock states, compared to the ABG as shown by 100% sensitivity for metabolic acidosis, metabolic alkalosis, and respiratory acidosis, with only marginally lower sensitivity (71%) for respiratory alkalosis. This study supports the use of utilizing a central VBG sample as a less invasive method for the diagnosis of acid-base disturbances in critically ill patients with central venous access.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Table 1

Overall Patient Characteristics and Laboratory Values.

Total N = 23 *	
Age (mean, SD)	62.5 (18.8)
Gender, male	39.1% (9)
Main diagnoses	
Respiratory (pneumonia, acute respiratory distress syndrome, respiratory failure)	45.5%
Sepsis/bacteremia	40.9%
Cardiac (heart failure, cardiac arrest)	13.6%
Vasopressor use	52.2% (12)
Hypotension	26.1% (6)
Mechanically ventilated	82.6% (19)
Renal replacement therapy	17.4% (4)
Acute kidney injury	69.6% (16)
Chemistry (median, IQR)	
Sodium (mmol/L)	139 (8)
Potassium (mmol/L)	4 (0.9)
Chloride (mmol/L)	110 (9)
Total CO ₂ (mmol/L)	20 (5)
BUN (mmol/L) [mg/dL]	13.2 (10.4) [37 (29)]
Creatinine (μmol/L) [mg/dL]	150.3 (123.8) [1.7 (1.4)]
Glucose (mmol/L)	7.9 (2.3)
Lactate (mmol/L)	0.16 (0.07)
Hemoglobin (mmol/L) [g/dL]	5.0 (0.9) [8.1 (1.5)]
SvO ₂ (%)	73.5 (12.4)
Pulse oxygenation (%)	99 (4)

* Number of paired ABG-central VBG results.

Table 2
Arterial and central venous blood gas values (n=23)

Reported median and range values.

Parameter	ABG	Central VBG
pH	7.35 (7.06 – 7.50)	7.33 (6.86 – 7.44)
pCO ₂ (mm Hg)	34 (19 – 71)	42 (23 – 73)
HCO ₃ (mmol/L)	21 (8.2 – 37.4)	21 (10.5 – 37.6)
<u>Assessed only in shock (n=13):</u>		
pH	7.28 (7.06 – 7.47)	7.25 (6.86 to 7.41)
pCO ₂ (mm Hg)	32 (24 – 55)	42 (30 – 63)
HCO ₃ (mmol/L)	17.4 (8.2 – 25.9)	18.8 (10.5 – 27.9)

Table 3

Diagnostic accuracy of central VBG-based diagnosis compared to ABG-based diagnosis.

Disorder [*]	Sensitivity	Specificity
Metabolic Acidosis (n=12)	100%	64%
Metabolic Alkalosis (n=2)	100%	100%
Respiratory Acidosis (n=8)	100%	60%
Respiratory Alkalosis (n=7)	71%	100%
No disorder (n=2)	0%	95%
Regardless of respiratory or metabolic origin:		
Disorder [*]	Sensitivity	Specificity
Acidosis (n=20)	100%	58%
Alkalosis (n=9)	78%	100%
Assessed only in shock states:		
Disorder [*]	Sensitivity	Specificity
Acidosis (n=16)	100%	67%
Alkalosis (n=2)	50%	100%

* Sample size of disorders defined using ABG-based diagnosis.

Table 4

Percent Agreement of central VBG-based diagnosis compared to ABG-based diagnosis.

Disorder *	Percent Agreement			
	Overall ^	Complete +	Partial §	None □
Metabolic Acidosis (n=12)	87.5%	75%	25%	0%
Metabolic Alkalosis (n=2)	75%	50%	50%	0%
Respiratory Acidosis (n=8)	94%	87.5%	12.5%	0%
Respiratory Alkalosis (n=7)	57%	43%	29%	29%
No disorder (n=2)	0%	0%	0%	100%
Regardless of respiratory or metabolic origin:				
Disorder *	Percent Agreement			
	Overall	Complete	Partial	None
Acidosis (n=20)	90%	75%	25%	0%
Alkalosis (n=9)	61.1%	44.4%	33.3%	22.3%
Assessed only in shock states (n=13):				
Disorder *	Percent Agreement			
	Overall	Complete	Partial	None
Acidosis (n=16)	91%	70%	30%	0%
Alkalosis (n=2)	25%	0%	50%	50%

* Sample size of disorders defined using ABG-based diagnosis.

^ : Overall agreement: (sum of complete agreement scores + sum of partial agreement scores) divided by sample size defined by the ABG-based diagnoses.

+ Complete agreement: number of central VBG diagnoses in complete agreement with ABG diagnoses divided by the sample size defined by ABG-based diagnoses.

§ Partial agreement: number of central VBG diagnoses in partial agreement with ABG diagnosis divided by the sample size defined by ABG-based diagnoses.

□ No agreement: number of central VBG diagnoses that had no level of agreement with ABG diagnosis divided by the sample size defined by ABG-based diagnoses.