



Original Article

Correlation between peripheral venous and arterial blood gas measurements in patients admitted to the intensive care unit: A single-center study



Bo Ra Kim, Sae Jin Park, Ho Sik Shin*, Yeon Soon Jung, Hark Rim

Department of Internal Medicine, Kosin University College of Medicine, Busan, Korea

A B S T R A C T

Article history:

Received 11 October 2012

Received in revised form

3 January 2013

Accepted 9 January 2013

Available online 29 January 2013

Keywords:

Bicarbonates

Blood gas analysis

Correlation

Intensive care units

Background: The objective of this study was to examine the correlation between arterial blood gas (ABG) and peripheral venous blood gas (VBG) samples for all commonly used parameters in patients admitted to a medical intensive care unit (ICU). **Methods:** A single-center, prospective trial was carried out in a medical ICU in order to determine the level of correlation of ABG and peripheral VBG measurements. A maximum of five paired ABG–VBG samples were obtained per patient to prevent a single patient from dominating the data set.

Results: Regression equations were derived to predict arterial values from venous values as follows: arterial pH = $-1.108 + 1.145 \times \text{venous pH} + 0.008 \times \text{PCO}_2 - 0.012 \times \text{venous HCO}_3 + 0.002 \times \text{venous total CO}_2$ ($R^2=0.655$), arterial $\text{PCO}_2 = 88.6 - 10.888 \times \text{venous pH} + 0.150 \times \text{PCO}_2 + 0.812 \times \text{venous HCO}_3 + 0.124 \times \text{venous total CO}_2$ ($R^2=0.609$), arterial $\text{HCO}_3 = -89.266 + 12.677 \times \text{venous pH} + 0.042 \times \text{PCO}_2 + 0.675 \times \text{venous HCO}_3 + 0.185 \times \text{venous total CO}_2$ ($R^2=0.782$). The mean ABG minus peripheral VBG differences for pH, PCO_2 , and bicarbonates were not clinically important for between-person heterogeneity.

Conclusion: Peripheral venous pH, PCO_2 , bicarbonates, and total CO_2 may be used as alternatives to their arterial equivalents in many clinical contexts encountered in the ICU.

© 2013. The Korean Society of Nephrology. Published by Elsevier. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

The acid–base and respiratory status of critical patients are commonly ascertained by means of arterial blood gas (ABG) analysis. Nevertheless, the test can cause patients to experience discomfort, and its associated complications include arterial injury, thrombosis or embolization, hematoma, aneurysm

formation, and reflex sympathetic dystrophy [1,2]. A further drawback for health care providers is the possibility of a needle stick injury when performing an ABG. A comparatively safer procedure is venous blood gas (VBG) analysis, which poses fewer risks to both the patients and health care professionals.

VBG may eventually take the place of ABG analysis in determining acid–base status. In contrast to earlier studies, which questioned the precision of VBG values [3–5], more recent evidences indicate a concurrence of ABG and VBG values [6–14]. However, as far as we can determine, the correlation between all parameters typically used in arterial and peripheral VBG samples as found in a broad population of

* Corresponding author. Department of Internal Medicine, Kosin University College of Medicine, 262 Gamcheon-ro, Seo-gu, Busan, 602–702, Korea.

E-mail address: danieljoseph@hanmail.net (HS Shin).

intensive care unit (ICU) patients has not been studied previously. An earlier study investigated whether the similarities between ABG and VBG values are sufficient for the respiratory and dynamic acid–base conditions. For this evaluation, each patient provided multiple paired ABG and VBG samples during the length of their ICU treatment.

The purpose of this study was to investigate the correlation of ABG and peripheral VBG samples for all common parameters (bicarbonate, total CO₂, pH, and PCO₂) in an ICU patient population exhibiting a variety of pathologies. Specific attention was given to the analysis of each patient's multiple paired arterial and venous samples.

Methods

A single-center, prospective trial was performed from April 2010 to September 2010 to evaluate the correlation of ABG and peripheral VBG measurements. The Kosin University Gospel Hospital ICU was the site of this study. The study involved every adult ICU patient who was found by the treating clinician to be in need of both ABG and peripheral VBG analysis. Cases where informed consent could not be obtained were excluded from the study. Samples were rejected if analysis showed them to be of venous rather than arterial origin. The study called for only minimal amounts of blood. Peripheral venous samples were taken in conjunction with (and within 2 minutes of) any ICU treatment that included an ABG analysis. ABG analysis was performed using ABG kit (BD Critical Care Collection; Becton Dickinson, Franklin Lakes, NJ, USA). A Nova Stat Profile CCX Blood Gas Analyzer (Nova Biomedical Corporation, Waltham, MA, USA) was used to analyze the samples. The analysis was performed as quickly as possible after obtaining the samples. To avoid any domination of the data set by a single patient, no more than five paired ABG–VBG samples were taken from each patient over 5 days. A standard data collection form was used. In addition to ABG–VBG statistics, data on primary diagnosis, intubation status, use of inotropic agents, hypotension (defined as a systolic blood pressure (BP) <90 mmHg), and peripheral venous total CO₂ values were obtained. Renal failure was defined as any of the following: increase in serum creatinine by ≥ 3.0 mg/L (≥ 26.5 μ mol/L) within 48 hours; increase in serum creatinine to ≥ 1.5 times baseline, which is known or presumed to have occurred within the prior 7 days; or urine volume <0.5 mL/kg/h for 6 hours. Patients' inclusion in the study was contingent upon their informed consent, and the Ethics Committee of Kosin University Gospel Hospital assessed and approved the study.

Agreement between arterial (A) and peripheral venous (V) measurements of pH, PCO₂, and bicarbonate was evaluated by the Bland–Altman method. The A–V difference was plotted against the average value [(A+V)/2]. The A–V differences were recorded in terms of means, standard deviations (SDs), and 95% prediction intervals (limits of agreement), in addition to the Pearson correlation between A–V and (A+V)/2. A correlation of 0 would indicate that no trend existed in the A–V differences. This study describes the Pearson correlations between ABG and peripheral VBG values. Equations for the estimation of arterial values from peripheral venous values were ascertained using linear regression. Components of variance computations were performed to detect any between-patient heterogeneity, which was necessary due to the use of multiple A and V measurements from individual patients. Additionally, in order to determine whether there was between-patient heterogeneity in the

regression analyses, a random slope and intercept model was used. The sample size of 34 patients was based on estimating the differences in peripheral venous minus arterial (lack of agreement) and their SD to within $\pm 23\%$ with 95% confidence for PCO₂, bicarbonate, or pH differences. SPSS version 18.0 (SPSS, Chicago, IL, USA) was used to conduct our statistical analyses. Results were judged to be significant when the $P < 0.05$.

Results

This study included 34 patients and a total of 151 paired ABG–VBG samples. Twenty-one paired samples were excluded, including 17 samples that were run on different blood gas analyzers and four samples where the arterial and venous samples were drawn >2 minutes apart. In total, 130 paired samples were included in the analysis. The patient characteristics are shown in Table 1. The test population was made up of 20 male (58.8%) and 14 female (41.2%) patients, with a mean \pm SD age of 65.5 ± 12.4 years. The most common presenting diagnosis was renal failure (67.6%), although several other conditions that are frequently encountered in the ICU were present. Among the participants, none were receiving bicarbonate, although the great majority were hypotensive (88.2%) and on inotropic agents (88.2%). Arterial versus peripheral venous intercept and slope homogeneity tests for pH, PCO₂, bicarbonate, and total CO₂ gave $P > 0.05$ (data not shown). Thus, all 130 observations could be combined (see the Discussion section). Arterial pH values were 6.97–7.56, patient arterial PCO₂ values 14–54 mmHg, and arterial bicarbonate values 3–36 mEq/L. Venous pH values were 7.14–7.53, venous PCO₂ values 18–52 mmHg, and venous bicarbonate values 6.4–73.1 mEq/L.

Table 2 shows the mean values and SDs for arterial and peripheral venous pH, PCO₂ and bicarbonate, as well as the arterial minus peripheral venous difference of these parameters. There was no significant difference in between-person heterogeneity in the A–V SD (Table 2). Pearson correlation coefficients

Table 1. Patient characteristics

Age (y; mean \pm standard deviation)	65.5 \pm 12.4
Gender (male/female; n, %)	20 (58.8)/14 (41.2)
Intubated (n, %)	8 (23.5)
Hypotensive (n, %)	30 (88.2)
Inotropic agent use (n, %)	30 (88.2)
Primary diagnosis (n, %)	
Sepsis	5 (14.7)
Upper GI bleeding	1 (2.9)
Renal failure	23 (67.6)
Pneumonia	1 (2.9)
Pancreatitis	2 (5.9)
Respiratory failure of unknown cause	2 (5.9)

GI, gastrointestinal.

Table 2. Mean \pm standard deviation (SD) arterial (A) and peripheral venous (V) blood gas values (n=130)

Parameter	ABG	VBG	A–V difference ^a
pH	7.426 \pm 0.074	7.397 \pm 0.677	0.030 \pm 0.050
PCO ₂ (mmHg)	30.8 \pm 6.5	34.6 \pm 6.9	–5.4 \pm 6.5
Bicarbonate (mEq/L)	20.32 \pm 4.8	21.83 \pm 6.94	–1.00 \pm 2.75

^a Total between-within-person SD. There was no significant difference in between-person heterogeneity in the A–V SD. ABG, arterial blood gas; VBG, venous blood gas.

between ABG and peripheral VBG measurements are shown in Table 3. Arterial pH, PCO₂, and HCO₃ were significantly correlated with venous pH, PCO₂, and HCO₃ ($P=0.0001$ for all; correlation coefficient=0.783, 0.705, and 0.846, respectively).

A Bland–Altman plot of arterial and peripheral venous blood pH, PCO₂, and HCO₃ showing the regression line (solid line) and the 95% limits of agreement (dotted lines) of the A–V difference is shown in Fig. 1 [A: 0.03 (SD 0.050), 95% limit (–0.184 to 0.311), $r=0.049$, $R^2=0.002$, B: –5.4 (SD 6.5), 95% limit (–0.328 to –0.006), $r=0.198$, $R^2=0.039$, C: –1.00 (SD 2.75), 95% limit (–0.429 to 0.242), $r=-0.054$, $R^2=0.003$]. The correlations between VBG and ABG values for pH, PCO₂, and HCO₃, between the peripheral VBG values for total CO₂ and ABG values for HCO₃, and between the peripheral VBG values for total CO₂ and for HCO₃ are shown in Fig. 2.

Table 3. Pearson correlation coefficients between arterial and peripheral VBG measurements

Variable	Pearson correlation coefficients	<i>P</i>
pH	0.783	0.0001
PCO ₂	0.705	0.0001
HCO ₃	0.846	0.0001

An assumption of data independence about linear and multiple linear regressions was confirmed by Durbin–Watson's test ($P < 0.05$, data not shown). Regression equations were derived to predict ABG values from peripheral VBG values, and are as follows:

$$\text{Arterial pH} = 0.763 \times \text{venous pH} + 1.786 \quad (R^2 = 0.544)$$

$$\text{Arterial PCO}_2 = 0.611 \times \text{venous PCO}_2 + 9.521 \quad (R^2 = 0.497)$$

$$\text{Arterial HCO}_3 = 0.822 \times \text{venous HCO}_3 + 2.815 \quad (R^2 = 0.716)$$

$$\text{Arterial HCO}_3 = 0.639 \times \text{venous total CO}_2 + 5.360 \quad (R^2 = 0.643)$$

$$\text{Venous HCO}_3 = 0.750 \times \text{venous total CO}_2 + 4.134 \quad (R^2 = 0.420)$$

In a subgroup analysis of renal failure patients only, regression equations were derived to predict ABG values from peripheral VBG values, and are as follows:

$$\text{Arterial pH} = 0.777 \times \text{venous pH} + 1.676 \quad (R^2 = 0.692)$$

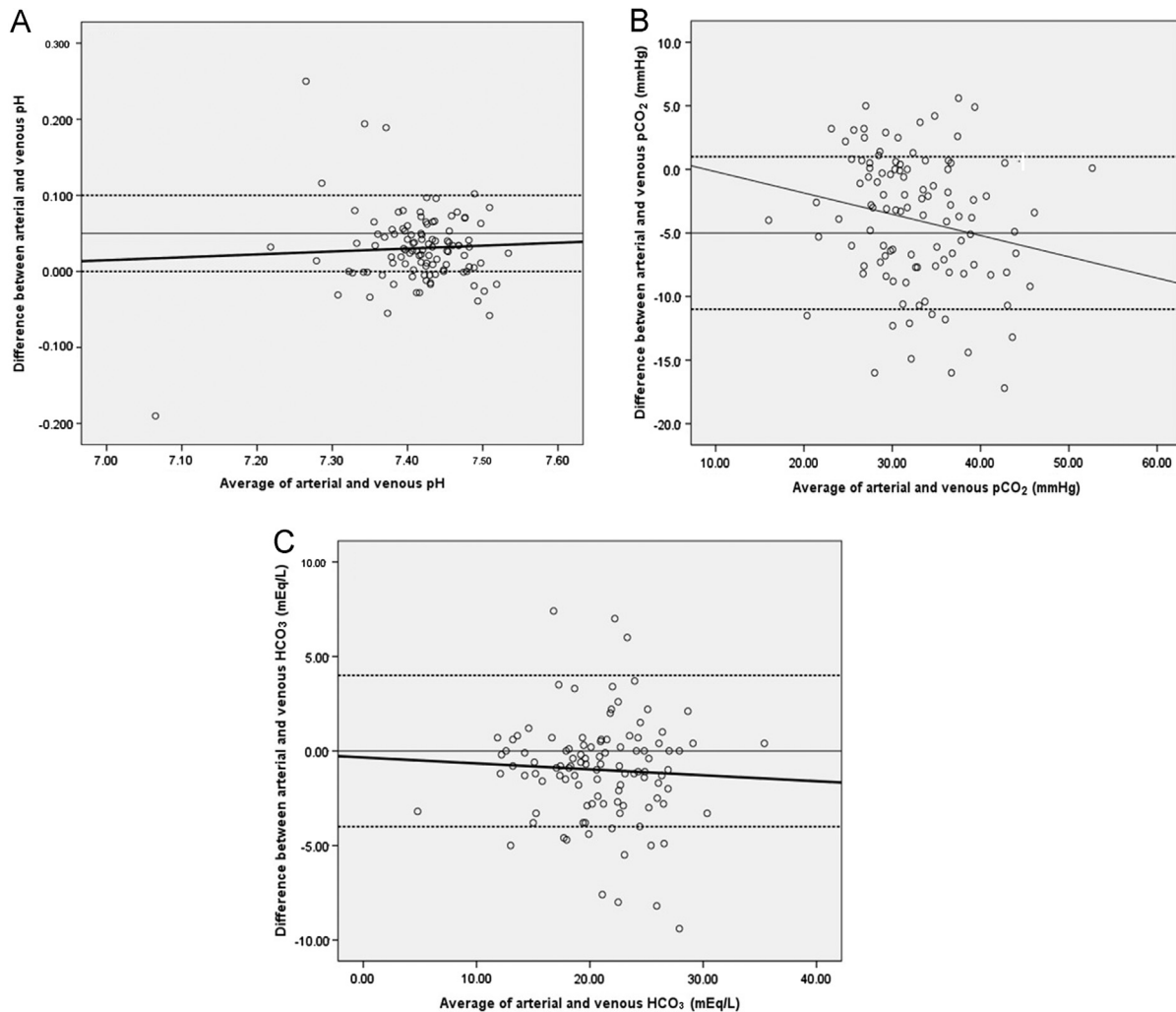


Figure 1. Bland–Altman plot of arterial and peripheral venous blood pH, PCO₂, and HCO₃ showing the regression line (solid line) and the 95% limits of agreement (dotted lines) for the A–V difference. $r=0.049$, $R^2=0.002$ (A); $r=0.198$, $R^2=0.039$ (B); $r=-0.054$, $R^2=0.003$ (C).

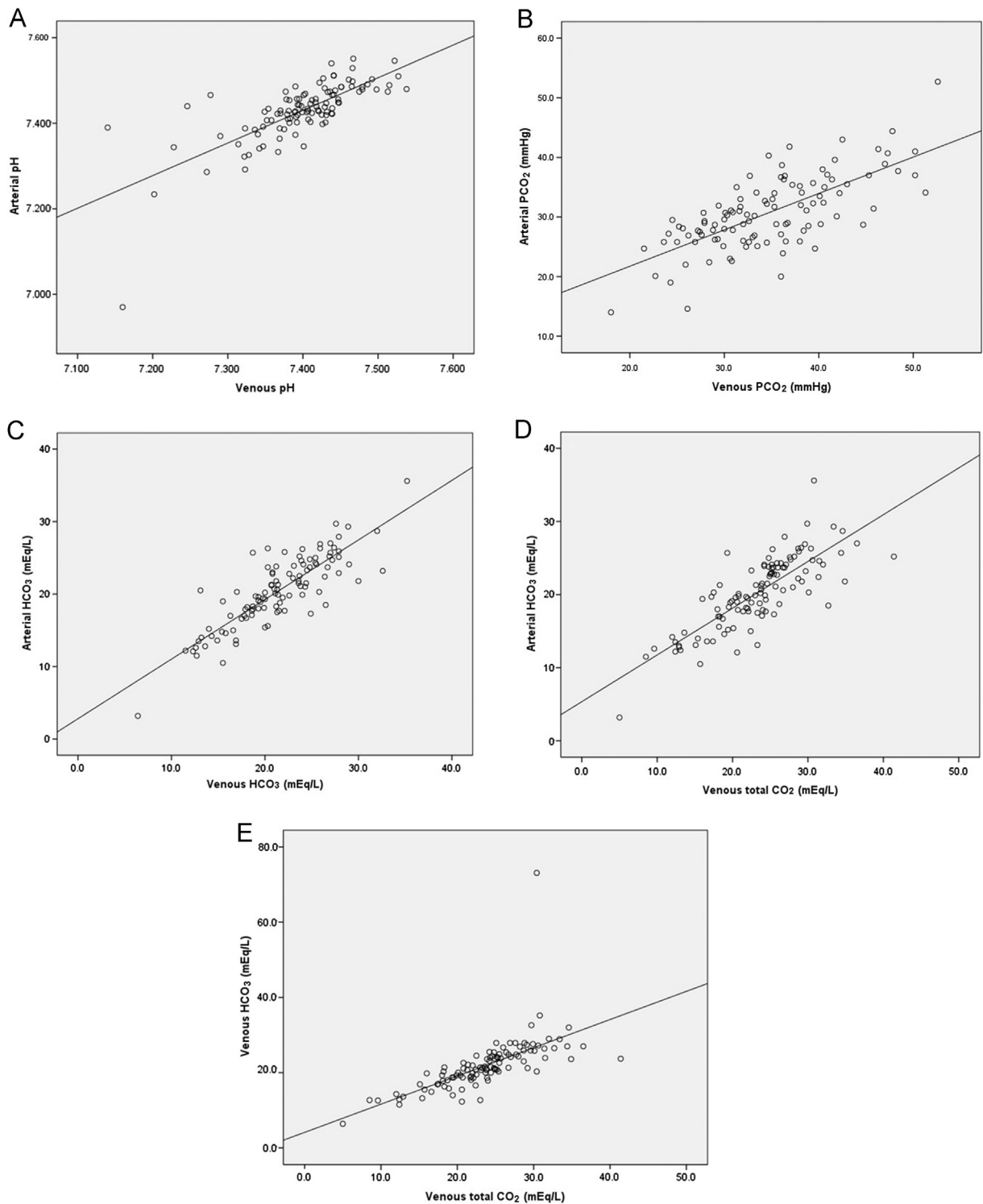


Figure 2. Correlation between peripheral venous (VBG) and arterial blood gas (ABG) values for pH, PCO₂, and HCO₃, between peripheral VBG values for total CO₂ and ABG values for HCO₃ and between peripheral VBG values for total CO₂ and for HCO₃. R²=0.544, arterial pH=0.763 × venous pH+1.786 (A); R²=0.497, arterial PCO₂=0.611 × venous PCO₂+9.521 (B); R²=0.716, arterial HCO₃=0.822 × venous HCO₃+2.815; (C); R²=0.643, arterial HCO₃=0.639 × venous total CO₂+5.360 (D); R²=0.420, venous HCO₃=0.750 × venous total CO₂+4.134 (E).

$$\text{Arterial PCO}_2 = 0.651 \times \text{venous PCO}_2 + 8.157 \quad (R^2 = 0.604)$$

$$\text{Venous HCO}_3 = 0.755 \times \text{venous total CO}_2 + 3.638 \quad (R^2 = 0.772)$$

$$\text{Arterial HCO}_3 = 0.912 \times \text{venous HCO}_3 + 0.891 \quad (R^2 = 0.823)$$

$$\text{Arterial HCO}_3 = 0.725 \times \text{venous total CO}_2 + 3.317 \quad (R^2 = 0.675)$$

Multivariate regression was used to establish whether using all four of the peripheral venous variables (pH, PCO₂, bicarbonate, and total CO₂) in a single equation could predict a patient's acid-base and respiratory status. Arterial

pH, PCO₂, HCO₃ and venous total CO₂ were significantly correlated with venous pH, PCO₂, and HCO₃ ($P=0.0001$ for all; correlation coefficients=0.783, 0.705, 0.846, and 0.725, respectively). The multivariate regression equations are as follows:

$$\text{Arterial pH} = -1.108 + 1.145 \times \text{venous pH} + 0.008 \times \text{PCO}_2 - 0.012 \times \text{venous HCO}_3 + 0.002 \times \text{venous total CO}_2 \quad (R^2=0.655)$$

$$\text{Arterial PCO}_2 = 88.6 - 10.888 \times \text{venous pH} + 0.150 \times \text{PCO}_2 + 0.812 \times \text{venous HCO}_3 + 0.124 \times \text{venous total CO}_2 \quad (R^2=0.609)$$

$$\text{Arterial HCO}_3 = -89.266 + 12.677 \times \text{venous pH} + 0.042 \times \text{PCO}_2 + 0.675 \times \text{venous HCO}_3 + 0.185 \times \text{venous total CO}_2 \quad (R^2=0.782)$$

In a subgroup analysis of renal failure patients only, multivariate regression was used to establish whether using all four of the peripheral venous variables (pH, PCO₂, bicarbonate, and total CO₂) in a single equation could be used to predict acid–base and respiratory status. The multivariate regression equations are as follows:

$$\text{Arterial pH} = 6.515 + 0.117 \times \text{venous pH} - 0.006 \times \text{PCO}_2 + 0.008 \times \text{venous HCO}_3 + 0.004 \times \text{venous total CO}_2 \quad (R^2=0.773)$$

$$\text{Arterial PCO}_2 = 606.1 - 81.485 \times \text{venous pH} - 0.797 \times \text{PCO}_2 + 2.264 \times \text{venous HCO}_3 + 0.316 \times \text{venous total CO}_2 \quad (R^2=0.771)$$

$$\text{Arterial HCO}_3 = 443.7 - 59.938 \times \text{venous pH} - 0.957 \times \text{PCO}_2 + 2.163 \times \text{venous HCO}_3 + 0.317 \times \text{venous total CO}_2 \quad (R^2=0.923)$$

Discussion

The aim of this study was to investigate the correlation between ABG and peripheral VBG samples for all commonly used parameters (pH, PCO₂, bicarbonate, and total CO₂) in a pathologically diverse ICU patient population. Peripheral venous pH, PCO₂, bicarbonates, and total CO₂ may be correlated with their arterial equivalents in many clinical contexts encountered in the ICU.

Based on the results of this study, ABG analysis is necessary in establishing precise PO₂ status, just as invasive arterial monitoring can still require arterial puncture. Nevertheless, the use of VBG analysis can lower the amount of arterial punctures needed for arterial sampling. In addition, the accuracy of pulse oximetry may offer a means of ascertaining acid–base status that is safer than ABG analysis and is also less likely to cause patient discomfort. Some previous studies have reported correlation between ABG and VBG values. However, certain limitations were inherent in most of those studies, including: examination of only one ABG and VBG sample per patient [6–14], analysis of only one or some parameters rather than all commonly used parameters (e.g., pH, PCO₂, and bicarbonate), or use of specific population samples (e.g., patients with diabetic ketoacidosis). In some cases, concerns have even been raised about the idea of using VBG values in place of arterial values [3–5].

Because the aim of this study was to investigate the correlation between ABG and peripheral VBG samples, we

did not check oxygen saturation data using an oximeter. Studies of pulse oximeter accuracy in populations of critically ill patients have reported mixed results [15]. However, if clinicians are aware of the bias and the wide limits of agreement when considering saturation data from oximeter readings in the many clinical contexts encountered in the ICU, oximeters might one day replace the PO₂ of ABG.

The presenting diagnosis for patients in the study was predominantly renal failure (67.6%), although there was a range of pathophysiologic parameters present. The patient population used in this study was fairly representative of the disease processes encountered in many medical ICUs. The results among patients with all diagnoses and also including only patients with renal failure were very similar (data not shown). Therefore, we included all diagnoses in the regression analysis. Further work is needed to study patients with other pathophysiologic states.

The present study is the first to investigate the extent to which a relationship between ABG and peripheral VBG pH, PCO₂, bicarbonate, and total CO₂ exists across patients. Differential CO₂ unloading at the tissue level could be attributed to patients' differing pathophysiologic states and other aspects inherent to each patient. For these reasons, a common relationship between ABG and peripheral VBG values in all patients cannot be inferred. Obtaining multiple paired arterial and peripheral venous samples from each patient allowed us to perform homogeneity tests, which revealed that the intercepts and slopes for pH, PCO₂, and bicarbonate in arterial versus venous blood had $P > 0.05$. Therefore, there was a common relationship between ABG and peripheral VBG pH, PCO₂, bicarbonate, and total CO₂ for all patients, allowing all 130 observations to be pooled for the remainder of the analysis.

We found excellent correlations between arterial and peripheral venous values for pH and bicarbonate, which is consistent with the results of previous studies [3–8,10–14]. In terms of pH, the mean arterial minus peripheral venous difference was 0.030 (SD 0.050) with a 95% limit of agreement of -0.184 to 0.311 (Fig. 1A). Previous studies have shown a mean arterial minus venous difference for pH ranging from -0.04 to 0.05 [3–8,10,12–14]. With respect to bicarbonate, the mean arterial minus peripheral venous difference was -1.00 (SD 2.75) with 95% limits of agreement of -0.429 to 0.242 (Fig. 1C). Previous studies have shown a mean arterial minus venous difference for bicarbonate ranging from -1.88 to -0.52 [3,4,6,7,11–14]. There was acceptable agreement between arterial and peripheral venous values for PCO₂; the mean arterial minus peripheral venous difference was -5.4 (SD 6.5) with 95% limits of agreement of -0.328 to -0.006 (Fig. 1B). Previous studies found a mean arterial minus venous difference for PCO₂ ranging from -6.6 to -3.0 [3,4,6,7,11–14]. The findings of the present study were generally consistent with earlier research in regards to PCO₂. In general practice, peripheral venous PCO₂ could be used in place of arterial PCO₂, taking into consideration that frequent serial blood gases are generally obtained to help assess a patient's course, and that blood gas values should be understood in the context of the individual patient's clinical status. Comparing the bivariate R² values to the multivariate R² values shows that the multivariate models may account for significantly more variation than the corresponding simple linear regression equations. This finding demonstrates that using the more complicated multivariate equations may be advantageous. For example, the

R^2 for arterial pH using only peripheral venous pH is 0.544. Using peripheral venous pH, peripheral venous PCO_2 , peripheral venous bicarbonate, and peripheral venous total CO_2 simultaneously to predict arterial pH increased the value to $R^2=0.655$.

Bicarbonate concentration is a measure that is widely used to assess the acid–base status of patients, and can be directly measured or derived using the Henderson–Hasselbalch equation. Bicarbonate ions make up ~95% of the total carbon dioxide of plasma [16]; therefore, they have been used interchangeably. Previous studies using different statistical methods to assess the correlation between measured and calculated bicarbonate values have shown conflicting results. Some studies have reported strong correlations [17,18], while a recent study did not find strong correlations between measured total CO_2 and calculated bicarbonate [19]. In our study, we found that there was a correlation between calculated arterial bicarbonate and measured peripheral venous total CO_2 ($R^2=0.643$).

We did not obtain central venous samples, and therefore cannot determine whether central venous samples have acceptable correlations with ABG values. In a recent study, data comparing central and peripheral VBG values showed that the mean central minus peripheral differences for pH, PCO_2 , and bicarbonate were not clinically important [20]. Therefore, we believe that central as well as peripheral venous samples have acceptable correlations with ABG values.

The present study investigated the correlation between all commonly used parameters in ABG and peripheral VBG samples in ICU patients and, to the best of our knowledge, is the first study to do so.

This study does have some limitations. First, inclusion in this study was extended to the first 34 patients who met the criteria. Random sampling was not used for selecting participants. However, this was not seen as a disadvantage because our patients fit the demographic of typical ICU test populations. Moreover, the study's arterial and venous values covered the range recognized as clinically important. Second, we noticed a pervasiveness in the occurrence of renal failure, despite the fact that test patients apparently typified the disease processes often found in the ICU. One consequence of this was an underrepresentation of other pathophysiologic states, such as cardiogenic shock and hypovolemic shock. Nevertheless, unless acute circulatory failure is present, there is little likelihood of such pathophysiologic conditions producing a different relationship between arterial and venous values. The results of this study can be generalized regardless of the predominance of patients with renal failure in our population. Although this study incorporated a wide range of acid–base status results (including arterial pH values of 6.97–7.56, arterial PCO_2 values of 14–54 mmHg, and arterial bicarbonate values of 3–36 mEq/L), values at the extremes were fewer in number. No more than five samples had a pH > 7.5, while only two samples showed a pH < 7. Third, if peripheral circulation is poor by various causes, results of VBG analysis should be carefully interpreted. Finally, hypotensive status is associated with an increase in the amount of difference between VBG and ABG analysis regarding pH and HCO_3^- [21]. In this study, the amount of difference between VBG and ABG analysis of four normotensive patients were smaller than that of hypotensive patients (data not shown). Studying the precise effects of replacing ABG with VBG on the clinical decision-making and the following outcomes is worthwhile.

In summary, peripheral venous pH, PCO_2 , bicarbonates, and total CO_2 may be used as alternatives to their arterial

equivalents in many clinical contexts encountered in the ICU. More work is needed to define further the relationships between ABG and peripheral VBG values in other pathophysiologic states.

Conflicts of interest

This study was supported by a grant from Roche Korea Co., Ltd. (2010).

Authors' contributions

SJ Park and HS Shin participated in the design of the study and performed the statistical analyses. YS Jung, BR Kim and H Rim conceived the study and participated in its design and coordination. All authors read and approved the final manuscript.

References

- [1] Mortensen JD: Clinical sequelae from arterial needle puncture, cannulation, and incision. *Circulation* 35:1118–1123, 1967
- [2] Criscuolo C, Nepper G, Buchalter S: Reflex sympathetic dystrophy following arterial blood gas sampling in the intensive care setting. *Chest* 108:578–580, 1995
- [3] Kelly AM, Kyle E, McAlpine R: Venous pCO_2 and pH can be used to screen for significant hypercarbia in emergency patients with acute respiratory disease. *J Emerg Med* 22:15–19, 2002
- [4] Rang LC, Murray HE, Wells GA, Macgougan CK: Can peripheral venous blood gases replace arterial blood gases in emergency department patients? *CJEM* 4:7–15, 2002
- [5] 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* 140:1122–1125, 2005
- [6] 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* 31:459–465, 1998
- [7] Gokel Y, Paydas S, Koseoglu Z, Alparslan N, Seydaoglu G: Comparison of blood gas and acid–base measurements in arterial and venous blood samples in patients with uremic acidosis and diabetic ketoacidosis in the emergency room. *Am J Nephrol* 20:319–323, 2000
- [8] 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* 18:340–342, 2001
- [9] Chu YC, Chen CZ, Lee CH, Chen CW, Chang HY, Hsiue TR: Prediction of arterial blood gas values from venous blood gas values in patients with acute respiratory failure receiving mechanical ventilation. *J Formos Med Assoc* 102:539–543, 2003
- [10] 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* 10:836–841, 2003
- [11] Kelly AM, McAlpine R, Kyle E: Agreement between bicarbonate measured on arterial and venous blood gases. *Emerg Med Australas* 16:407–409, 2004
- [12] 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. *Tohoku J Exp Med* 210:285–290, 2006
- [13] 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* 23:622–624, 2006

- [14] Malatesha G, Singh NK, Bharija A, Rehani B, Goel A: Comparison of arterial and venous pH, bicarbonate, PCO_2 and PO_2 in initial emergency department assessment. *Emerg Med J* 24:569–571, 2007
- [15] Wilson BJ, Cowan HJ, Lord JA, Zuege DJ, Zygun DA: The accuracy of pulse oximetry in emergency department patients with severe sepsis and septic shock: a retrospective cohort study. *BMC Emerg Med* 10:1–6, 2010
- [16] Scott MG, LeGrys VA, Klufts JC: Electrolytes and blood gases. In: Burtis CA, Er Ashwood, Bruns DE, editors. *Tietz Textbook of Clinical Chemistry*. 4th edition. Missouri: Elsevier; p. 985, 2006
- [17] Chittamma A, Vanavanan S: Comparative study of calculated and measured total carbon dioxide. *Clin Chem Lab Med* 46:15–17, 2008
- [18] Kumar V, Karon BS: Comparison of measured and calculated bicarbonate values. *Clin Chem* 54:1586–1587, 2008
- [19] Nasir NM, Sthaneshwar P, Yunus PJ, Yap SF: Comparing measured total carbon dioxide and calculated bicarbonate. *Malays J Pathol* 32:21–26, 2010
- [20] 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* 5:390–394, 2010
- [21] Shirani F, Salehi R, Naini AE, Azizkhani R, Gholamrezaeid A: The effects of hypotension on differences between the results of simultaneous venous and arterial blood gas analysis. *J Res Med Sci* 16:188–194, 2011