

Can peripheral venous blood gases replace arterial blood gases in emergency department patients?

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ABSTRACT

Objective: To determine if peripheral venous blood gas values for pH, partial pressure of carbon dioxide (P_{CO_2}) and the resultant calculated bicarbonate (HCO_3^-) predict arterial values accurately enough to replace them in a clinical setting.

Methods: This prospective observational study was performed in a university tertiary care emergency department from June to December 1998. Patients requiring arterial blood gas analysis were enrolled and underwent simultaneous venous blood gas sampling. The following data were prospectively recorded: age, sex, presenting complaint, vital signs, oxygen saturation, sample times, number of attempts and indication for testing. Correlation coefficients and mean differences with 95% confidence intervals (CIs) were calculated for pH, P_{CO_2} and HCO_3^- . A survey of 45 academic emergency physicians was performed to determine the minimal clinically important difference for each variable.

Results: The 218 subjects ranged in age from 15 to 90 (mean 60.4) years. The 2 blood samples were drawn within 10 minutes of each other for 205 (96%) of the 214 patients for whom data on timing were available. Pearson's product-moment correlation coefficients between arterial and venous values were as follows: pH, 0.913; P_{CO_2} , 0.921; and HCO_3^- , 0.953. The mean differences (and 95% CIs) between arterial and venous samples were as follows: pH, 0.036 (0.030–0.042); P_{CO_2} , 6.0 (5.0–7.0) mm Hg; and HCO_3^- , 1.5 (1.3–1.7) mEq/L. The mean differences (± 2 standard deviations) were greater than the minimum clinically important differences identified in the survey.

Conclusions: Arterial and venous blood gas samples were strongly correlated, and there were only small differences between them. A survey of emergency physicians suggested that the differences are too large to allow for interchangeability of results; however, venous values may be valid if used in conjunction with a correction factor or for trending purposes.

RÉSUMÉ

Objectif : Déterminer si les valeurs des gaz du sang veineux périphérique pour le pH, la pression partielle du gaz carbonique (P_{CO_2}) et la concentration de bicarbonates résultante calculée (HCO_3^-) permettent de prédire les valeurs artérielles avec suffisamment de précision pour les remplacer dans un contexte clinique.

Méthodes : Cette étude observationnelle prospective fut menée dans un département d'urgence universitaire de soins tertiaires de juin à décembre 1998. Les patients nécessitant une analyse des gaz du sang artériel furent inclus dans l'étude et furent soumis à un échantillonnage simultané des gaz du sang veineux. Les données suivantes furent notées de manière prospective : âge, sexe,

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raison de consultation, signes vitaux, saturation en oxygène, délais pour les prélèvements, nombre de tentatives et indication pour le test. Les coefficients de corrélation et les différences moyennes avec des intervalles de confiance à 95 % (IC) furent calculés pour le pH, le P_{CO_2} et le HCO_3^- . Un sondage auprès de 45 médecins d'urgence enseignants fut effectué afin de déterminer la différence minimale cliniquement significative pour chaque variable.

Résultats : L'âge des 218 sujets s'échelonnait de 15 à 90 ans (âge moyen 60,4 ans). Les deux échantillons de sang furent prélevés dans un intervalle de moins de dix minutes chez 205 (96 %) des 214 patients pour qui les données de délais étaient disponibles. Les coefficients de corrélation produit-moment de Pearson entre les valeurs artérielles et veineuses étaient les suivants : pH, 0,913; P_{CO_2} , 0,921; et HCO_3^- , 0,953. Les différences moyennes (et IC à 95 %) entre les échantillons artériels et veineux étaient les suivants : pH, 0,036 (0,030–0,042); P_{CO_2} , 6,0 (5,0–7,0) mm Hg; et HCO_3^- , 1,5 (1,3–1,7) mEq/L. Les différences moyennes (± 2 écarts types) étaient supérieures aux différences minimales cliniquement significatives identifiées dans le sondage.

Conclusions : Il y avait une forte corrélation entre les échantillons des gaz du sang artériel et du sang veineux et les différences entre ceux-ci étaient minimes. Un sondage auprès des médecins d'urgence suggère que les différences sont trop importantes pour que les résultats soient interchangeables; cependant, les valeurs veineuses peuvent être valables si elles sont utilisées de pair avec un facteur de correction ou pour des fins d'orientation.

Key words: blood gas analysis, diagnosis, acidosis, acid–base equilibrium

Introduction

Acid–base analysis is an essential tool in emergency medicine, yielding valuable information about a variety of disease processes. Arterial blood gas (ABG) analysis is the gold standard method for acquiring this information. Although used to evaluate many respiratory and metabolic conditions, ABG analysis is not without drawbacks. The most common complication associated with arterial puncture is local hematoma, and, very rarely, arterial dissection and thrombosis may occur.^{1,2} The procedure itself can be technically difficult, particularly in children and elderly patients, and several attempts may be required. It is also painful, particularly when performed in the radial artery at the wrist.

Peripheral venous blood gas sampling may be a useful alternative to ABG sampling. Venous blood is easier to obtain, the procedure is less painful, and the sample may be drawn simultaneously with samples for other laboratory tests. Venous sampling eliminates the risks of arterial hematoma, dissection and thrombosis.^{1,2} Several studies have shown good correlation between arterial and peripheral venous blood gas samples, but authors have differed with respect to whether venous gas analysis can replace arterial gas analysis.^{3–8} In one study that showed high correlation, Gennis and colleagues⁷ were hesitant to endorse venous sampling alone because of the range of differences between venous and arterial values. In another study, involving patients with diabetic ketoacidosis, Brandenburg and Dire⁸ documented similar differences but came to the opposite conclusion, recommending the use of venous blood gas analysis.

The purpose of this study was to prospectively examine the correlations and mean differences between simultaneous arterial and peripheral venous blood gas values in emergency department (ED) patients, and to determine whether peripheral venous blood gas values predict arterial values accurately enough to replace them in a clinical setting.

Methods

Setting and subjects

This study was conducted at Kingston General Hospital, an academic tertiary care facility with an emergency medicine residency program, an annual census of more than 50 000 visits and an admission rate of approximately 18%. All adult patients who required ABG sampling on the basis of their clinical presentation were eligible for the study, but patients presenting during the chemistry laboratory's peak time of 0400–0800 were excluded because of the potential backlog associated with running double samples. Verbal informed consent was obtained from eligible patients or the relatives of incapacitated patients, and the study protocol was approved by our institution's Research Ethics Board.

Sample size

Assuming a Pearson product–moment correlation coefficient (r) of 0.9, as defined by Brandenburg and Dire,⁸ we determined that a sample of 200 patients would provide a sufficiently narrow confidence range (0.89–0.94) around the point estimate for r . This sample size was feasible in our ED within a 6-month study period.

Data collection

Attending or resident emergency physicians who drew radial, brachial or femoral arterial blood samples completed a data form documenting the clinical indication for testing, the site and time of sampling, and the number of attempts required. As soon as possible after the arterial sample was taken, a nurse drew a venous sample with the tourniquet in place. In the event of unsuccessful venipuncture, another limb was used for sampling. Nurses recorded the sample site, sample time and tourniquet time. The 2 samples were collected in identical heparinized syringes (Vacutainer brand Preset syringes, Becton, Dickinson and Co., Franklin Lakes, NJ), and the syringes were labelled and sent to the laboratory on ice via a pneumatic tube system. Tests were run on the Radiometer ABL 500 and 520 series blood gas analysis machine (Radiometer, Copenhagen, Denmark). Only the ABG results were available to the physician, to avoid any changes in practice during the study period.

For each patient, the following information was collected: age, sex, vital signs, oxygen saturation, medications, inspired oxygen concentration, presenting complaint and discharge diagnosis. The venous and arterial sample pH, partial pressure of carbon dioxide (P_{CO_2}) and resultant calculated bicarbonate (HCO_3) were recorded. To estimate

the enrolment rate and to examine potential selection bias, seven 6-day intervals during the 6-month study period were randomly selected by means of 2 dice. The first die defined a month and the second a predefined 6-day period within that month. All ED patients who had undergone ABG testing during these periods were identified through the laboratory's database, and the patient characteristics and ABG results of patients not enrolled in the study were subsequently compared with those for patients who were enrolled.

Defining clinically important differences

To determine the acceptable level of difference between arterial and venous values, 45 board-certified emergency physicians from 2 academic centres were surveyed. The physicians were asked to answer the following question for all 3 blood gas variables (pH, P_{CO_2} and HCO_3): "I would feel uncomfortable using only the venous value for clinical decisions if it was more than ___ units away from the arterial value." The survey was distributed to the physicians through their mailboxes, and 2 written reminders were sent.

Data analysis

Means and 95% confidence intervals (CIs) were calculated

Table 1. Patient characteristics, indications for testing and test results for enrolled patients and eligible patients who were not enrolled

Characteristic, indication or result	Enrolled (n = 218)		Not enrolled (n = 62)		p
Patient characteristics					
Male sex, no. (and %)	113	(52%)	25	(40%)	NS
Mean age (and SD), yr	60.4	(18.9)	63.9	(19.0)	NS
Age range, yr	15–90		21–97		NS
Heart rate > 110 beats/min, no. (and %)	68	(31%)	16	(26%)	NS
Systolic BP < 90 mm Hg, no. (and %)	5	(2%)	4	(6%)	NS
Respiratory rate > 20 breaths/min, no. (and %)	163	(75%)	46	(74%)	NS
Oxygen saturation < 90%*	30	(14%)	17	(27%)	NS
Indication for blood gas analysis					
Respiratory problem, no. (and %)	179	(82%)	43	(69%)	0.03
Metabolic problem, no. (and %)	31	(14%)	17	(27%)	0.02
Toxicological problem, no. (and %)	8	(4%)	2	(3%)	NS
Arterial blood gas results (and 95% CI)					
Mean pH	7.39	(7.38–7.40)	7.40	(7.37–7.43)	NS
Mean P_{O_2} , mm Hg	98.6	(90.8–106.4)	90.5	(78.3–102.7)	NS
Mean P_{CO_2} , mm Hg	43.5	(41.1–45.9)	42.1	(37.9–45.1)	NS
Mean HCO_3 , mEq/L	22.6	(21.8–23.3)	22.8	(21.3–24.3)	NS
Venous blood gas results (and 95%CI)					
Mean pH	7.35	(7.34–7.37)		NA	
Mean P_{CO_2} , mm Hg	49.6	(47.3–51.9)		NA	
Mean HCO_3 , mEq/L	24.0	(23.3–24.7)		NA	

SD = standard deviation; NS = not significant; BP = blood pressure; CI = confidence interval; P_{O_2} = partial pressure of oxygen; P_{CO_2} = partial pressure of carbon dioxide; HCO_3 = bicarbonate; NA = not available.

*Oxygen saturation values include data for patients receiving supplemental oxygen and patients on room air and may therefore underestimate the actual degree of hypoxia.

for each arterial and venous variable (pH, P_{CO_2} and HCO_3) and for the differences between them. Pearson product-moment correlation coefficients were also calculated for each of the measured blood gas variables. A graphical method of examining agreement, first published by Bland and Altman in 1986,⁹ was used to display the range and degree of the differences between the venous and arterial measurements. Mean values and 95% CIs were calculated for the results of the survey on clinically important differences. The mean ABG values of the eligible but missed patients were compared with those entered in the study using Student's *t*-test. All statistical tests were performed with the Statistical Package for the Social Sciences (SPSS version 9.0 for Windows, SPSS Inc., Chicago).

Results

Two hundred and eighteen patients were enrolled between July and December 1998. On the basis of the random analysis of missed patients, we estimate that 40% of eligible patients were enrolled in the study and that 4% of eligible patients were excluded because they presented between 0400 and 0800. Table 1 shows that demographic, clinical and blood gas variables were similar between the 2 groups, which suggests that enrolled patients were not systematically different from eligible patients who were not enrolled. Most of the patients were hemodynamically stable; however, several patients presented with respiratory distress. Shortness of breath was the most common indication for ABG analysis (179 patients [82%]), whereas investigation of potential metabolic problems such as diabetic ketoacidosis, renal failure, seizures, decreased level of consciousness and ischemic colitis accounted for 31 (14%) of the tests. The remaining 8 patients (4%) had suspected ingestion of toxic materials.

Of the 214 patients for whom time data were complete, 187 (87%) had arterial and venous samples drawn within 5 minutes of each other, 205 (96%) had samples drawn within 10 minutes, and all had samples drawn within 30 minutes. Venous tourniquet time was 3 minutes or less for 146 (94%) of the 156 patients for whom tourniquet time was recorded.

Twenty-six (58%) of the 45 physicians responded to the survey. Figure 1 summarizes the respondents' opinions regarding what constitutes a clinically important difference between venous and arterial results. The mean clinically important differences (and 95% CIs) were 0.05 (0.04–0.06) units for pH, 6.6 (5.6–7.6) mm Hg for P_{CO_2} and 3.5 (3.1–4.0) mEq/L for HCO_3 .

Figures 2A, 2B and 2C demonstrate excellent correlation

between arterial and venous pH, P_{CO_2} and calculated HCO_3 . The mean differences (and 95% CIs) between arterial and venous samples were 0.036 (0.030–0.042) units for pH, 6.0 mm Hg (5.0–7.0) mm Hg for P_{CO_2} , and 1.5 (1.3–1.7) mEq/L for HCO_3 .

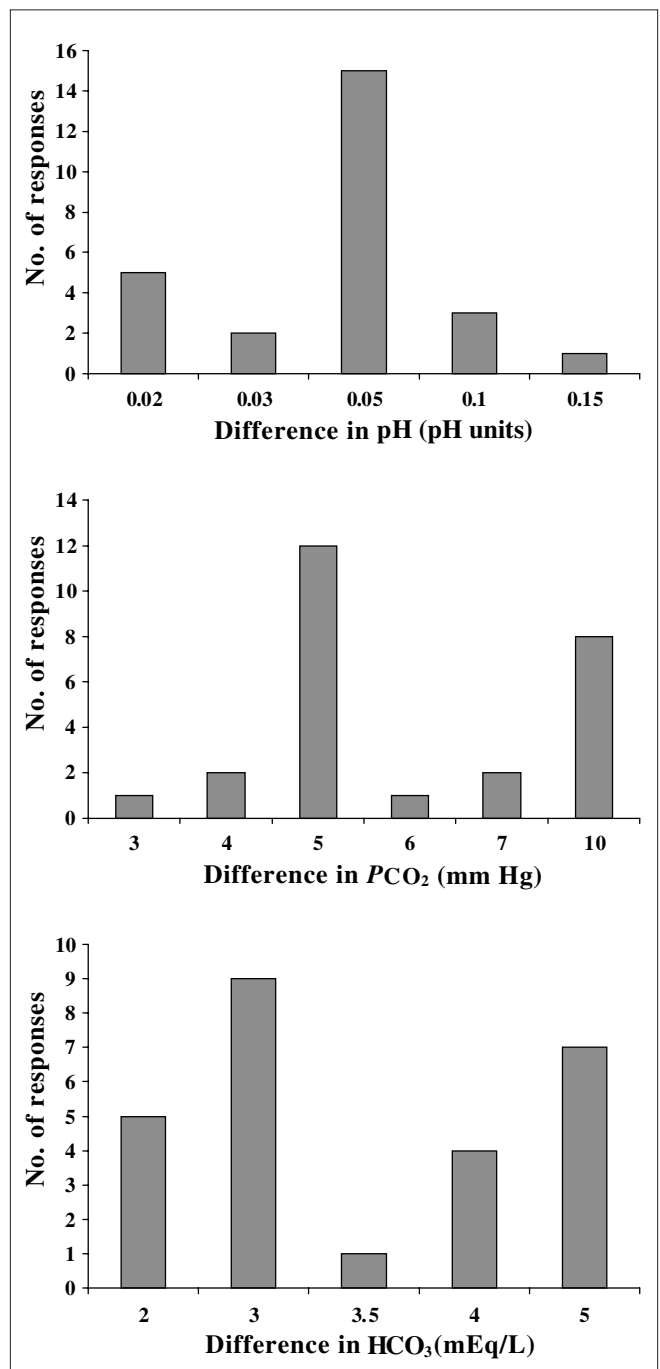


Fig. 1. Frequency histogram displaying the differences in pH, partial pressure of carbon dioxide (P_{CO_2}) and bicarbonate (HCO_3) between venous and arterial samples that were considered clinically important by a sample of 26 emergency physicians.

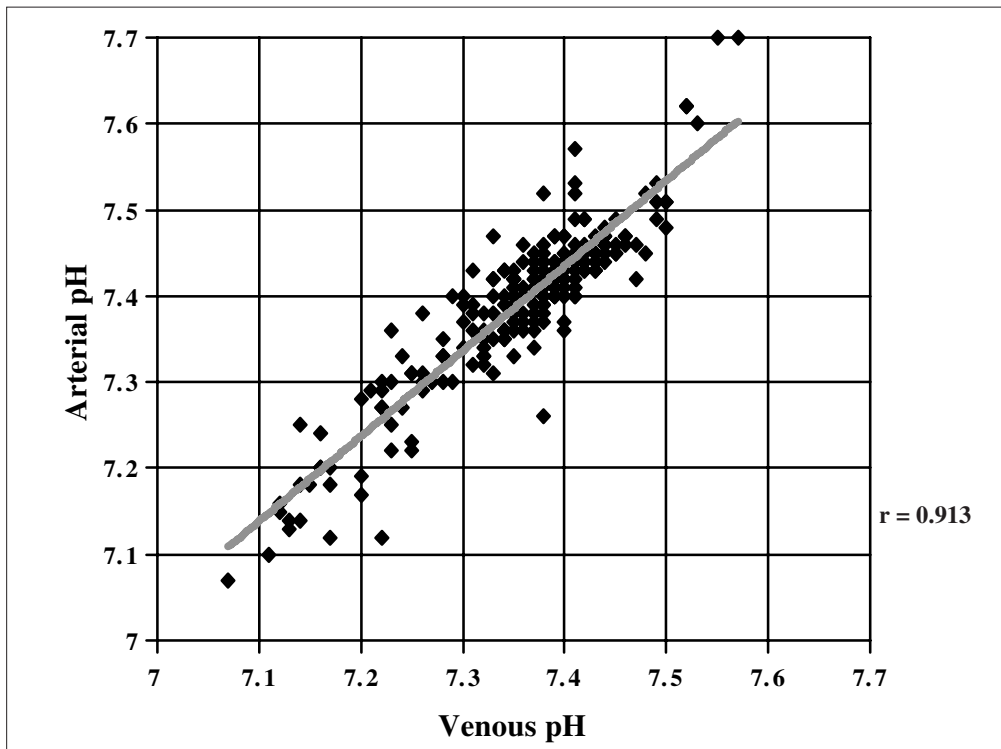


Fig. 2A. Correlation between venous and arterial pH values. The Pearson product-moment correlation (r) measures the strength of the association between 2 variables. If there was perfect correlation ($r = -1$ or 1), all points would fall along the straight diagonal line.

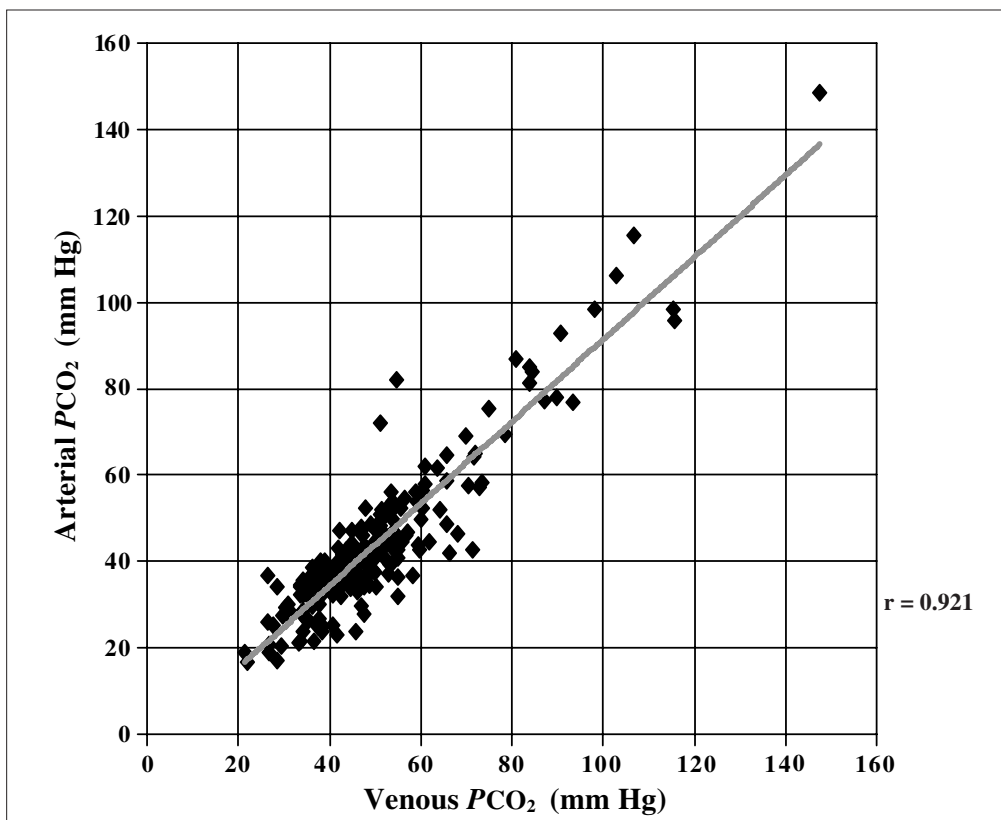


Fig. 2B. Correlation between venous and arterial PCO_2 values.

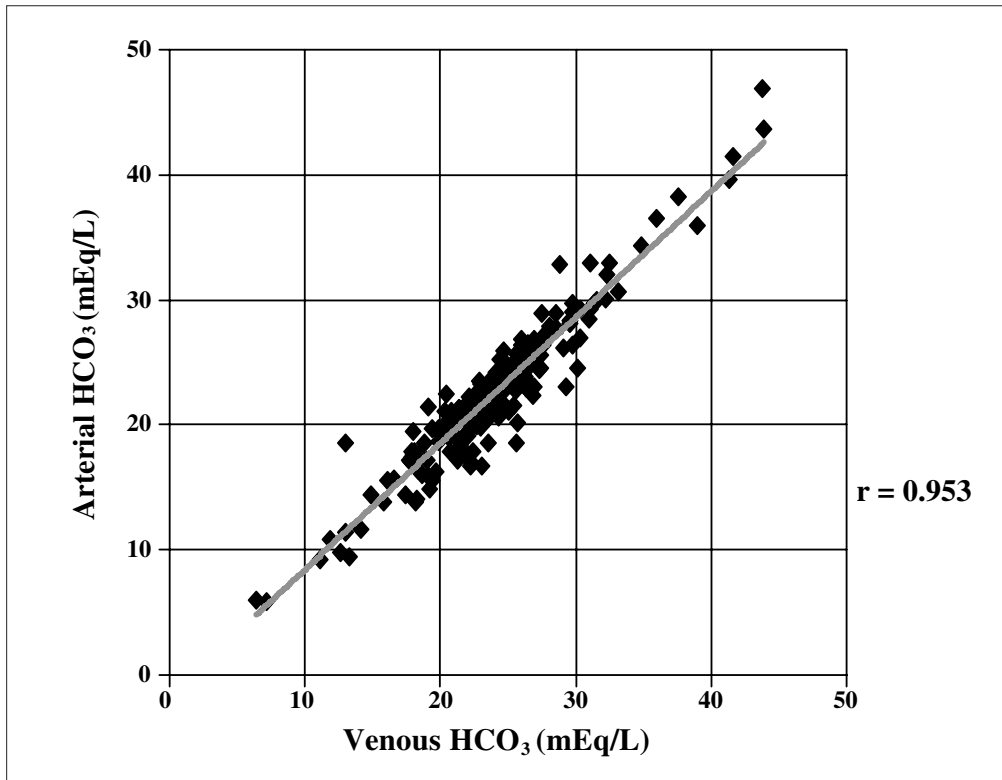


Fig. 2C. Correlation between venous and arterial HCO₃ values.

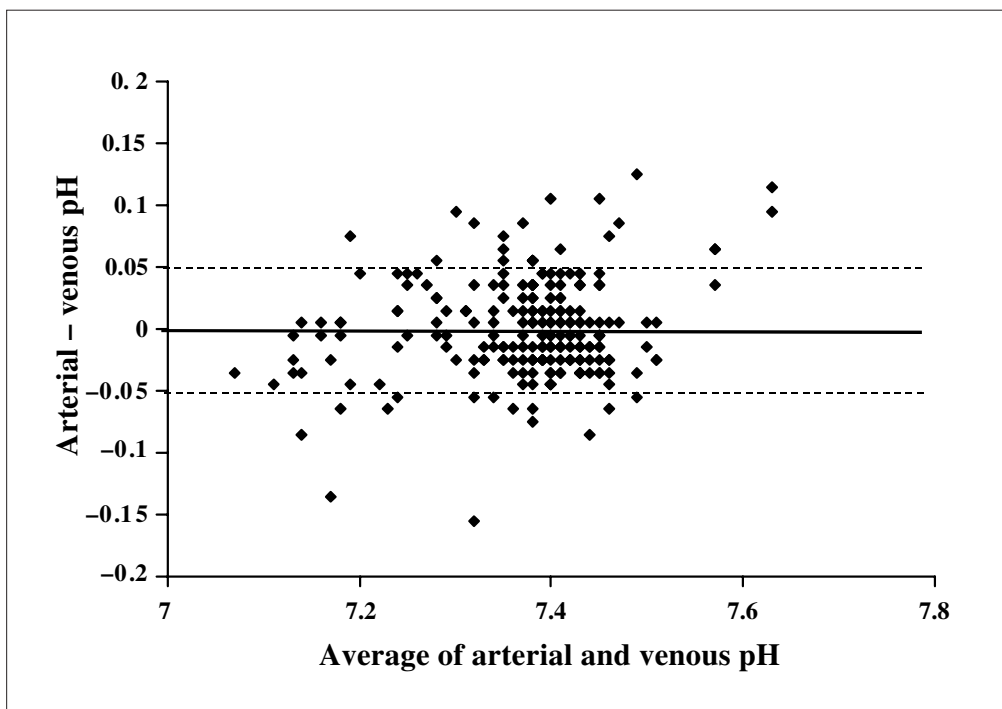


Fig. 3A. Agreement between venous and arterial pH values. For each patient the difference between arterial and venous values is plotted against the mean of the 2 values; thus, identical arterial and venous values fall along the zero line. The dashed lines represent the minimal clinically important difference above and below zero, as defined by respondents to our survey.

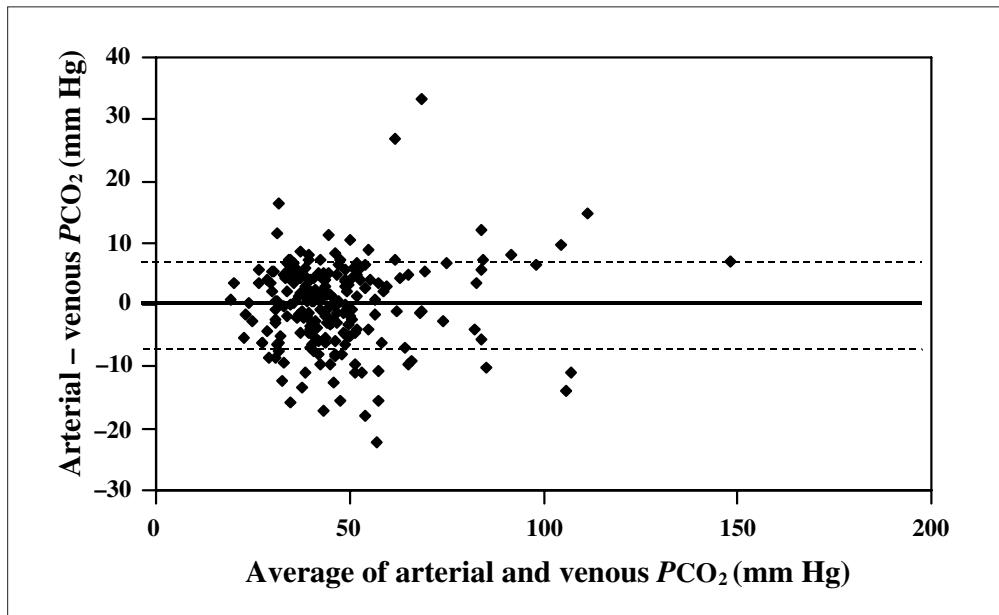


Fig. 3B. Agreement between venous and arterial PCO_2 values.

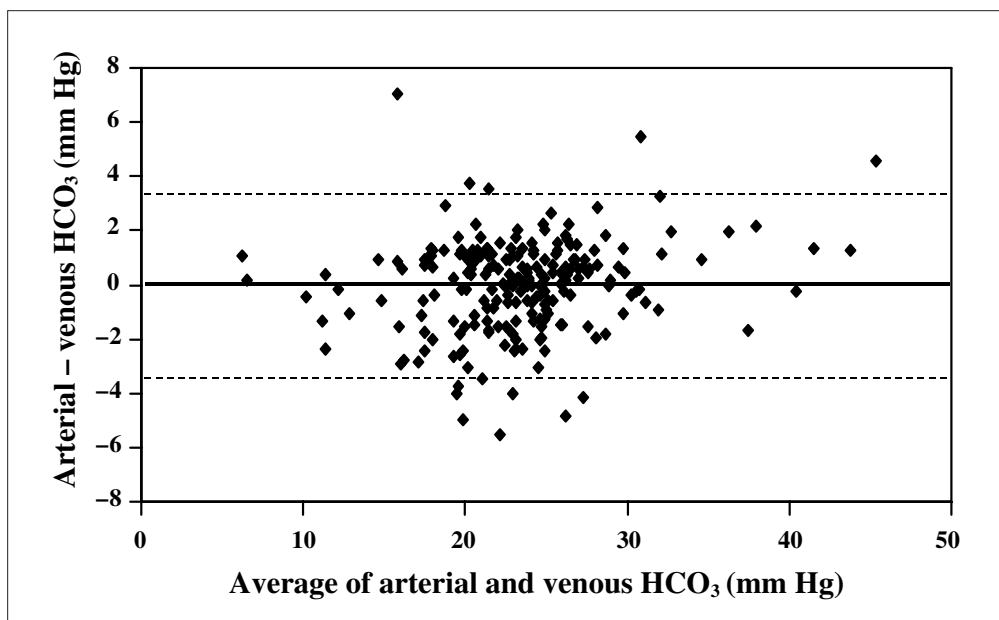


Fig. 3C. Agreement between venous and arterial HCO_3 values.

Figures 3A, 3B and 3C show a graphical method of assessing the agreement between 2 variables, as described by Bland and Altman.⁹ We have modified the original Bland and Altman plots so that the dashed lines above and below the zero line represent the minimal clinically important differences derived from the physician survey, rather than the 2 standard deviation (SD) levels generally used in plots of this type. Consequently, data points that

fall outside these lines represent a paired sample in which the difference between arterial and venous results was greater than the minimal clinically important difference for that variable. In Figure 3A, 144 (66%) of the pH differences fall within the acceptable defined limits. In Figure 3B, 112 (51%) of the PCO_2 differences fall within this range, and in Figure 3C, 190 (87%) of the differences are acceptable.

Discussion

Peripheral venous blood gas sampling is an attractive alternative to arterial sampling, for the reasons outlined earlier. Our data show strong correlation and small mean differences between arterial and venous values for pH, PCO_2 and HCO_3 .

Correlation vs. agreement

The Pearson product-moment correlation coefficients (r) presented in Figures 2A, 2B and 2C are all greater than 0.9, representing excellent correlation. However, this statistic simply measures the strength of the relation between 2 variables; it is not a measure of agreement between them.⁹⁻¹¹ Our data show a strong linear relation between venous and arterial blood gas samples, but for one type of sample to replace another, agreement between the parameters should also be high. To illustrate the difference between correlation and agreement, let us take the example of a thermometer that consistently reads 20° below the actual temperature; the readings from this thermometer would have excellent correlation but poor agreement with the actual temperature.

A graphical way to measure agreement was first described by Bland and Altman, and it is their description upon which Figures 3A, 3B and 3C are based.^{9,10} The average of the 2 measurements (arterial and venous) is taken as the best estimate of “truth” and is plotted against the difference between the samples. Essentially, then, the pH graph (Fig. 3A) shows the magnitude and direction of differences between pairs over a broad pH range. The PCO_2 and HCO_3 graphs (Figs. 3B and 3C) illustrate the same principle. The differences are not surprising, with venous pH generally lower than arterial and venous PCO_2 generally higher than arterial. The mean venous HCO_3 was, however, unexpectedly higher than the mean arterial value. We conclude that HCO_3 , a calculated value, was influenced more by the CO_2 level on which the calculation is based than by the pH. This would drive the calculated HCO_3 levels above the expected value. Serum bicarbonate is, therefore, more accurately quantified when measured directly as part of an electrolyte assay.¹²

Clinically important differences

Bland and Altman⁹ have stated that if the mean difference between 2 values (± 2 SD) is not clinically important, the 2 measurements could be used interchangeably. In our study, the “2 SD ranges” (around mean differences between arterial and venous values) were as follows: ± 0.08 pH units, ± 13.9 mm Hg for PCO_2 and ± 3.5 mEq/L for bicarbonate, similar to those defined in previous studies.^{7,8}

Because SD is a statistical concept and of uncertain relevance in this setting, we surveyed physicians to determine the magnitude of *clinically* acceptable differences. These clinicians thought that differences of ± 0.05 pH units, ± 6.6 mm Hg for PCO_2 and ± 3.5 mEq/L for HCO_3 were important. However, only 66% of the pH values, 51% of the PCO_2 values and 87% of the HCO_3 values in our study fell within these “acceptable” ranges. In order to encompass 95% of the differences, physicians would have to be willing to accept a range of disagreement of ± 0.08 pH units, ± 13.9 mm Hg for PCO_2 and ± 3.5 mEq/L for HCO_3 (i.e., 2 SD).

This limited survey suggests that emergency physicians may not be comfortable with the level of disagreement between venous and arterial samples. However, our survey defined the desired level of agreement necessary if venous and arterial gases were to be used interchangeably. These data confirm that venous and arterial results are not equivalent and that single values cannot be used interchangeably; however, the use of a correction factor derived from data in this and other studies might allow physicians to adjust venous results to derive values within acceptable tolerance levels.

The fundamental question in interpreting these data is how the information obtained from these samples can be used to make clinical decisions. If an exact value is needed to make a decision, then agreement between arterial and venous results must be excellent. However, individual blood gas values do not drive treatment decisions in the way, for example, that acetaminophen levels do. The primary value of blood gas monitoring is in identifying trends over time. For example, rising carbon dioxide levels in a patient with respiratory distress or falling HCO_3 levels and pH in a patient with ketoacidosis might lead to changes in management. The phenomenal correlation between arterial and venous blood gas values observed in this study suggests that, even though the absolute values may differ slightly, changes in venous gases from a baseline value would accurately reflect changes in the corresponding arterial values and could therefore be used for trending purposes.

Limitations

Although we attempted to enroll patients consecutively, our review of the study period suggests that we enrolled only 40% of eligible patients. In a comparison of the enrolled patients with a random sample of those who were eligible but not enrolled, we were unable to find any differences between the 2 groups, which suggests that our results could be generalized to the entire ED population. All previously published work in this area was performed on patients obtained by convenience sampling, without comparisons between enrolled and non-enrolled patients.^{7,8}

Our survey of emergency physicians represented a small sample within a localized area. A larger survey of a more diverse sample of emergency physicians might have yielded different results. In addition, the survey was carried out in an abstract manner that did not attempt to measure real differences in clinical decision-making, given specific arterial vs. venous values. Further research should focus on whether the absolute differences between venous and arterial gas values affect clinical decisions and outcomes.

Conclusions

Venous and arterial blood gas results are highly correlated, but the small mean differences between them may preclude using such results interchangeably. Given the excellent correlation, venous gases will be accurate for trend monitoring or for broader ED use with a redefined set of normal values.

Competing interests: None declared.

Authorship: Dr. Rang was responsible for the development of the study protocol, data collection, and analysis and writing of the manuscript. Dr. Murray supervised all aspects of the project and the manuscript writing. Dr. Wells provided statistical and methodologic support for both study design and data analysis. Mr. Macgougan assisted Dr. Rang in data collection and analysis.

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