Agreement between mathematically arterialised venous versus arterial blood gas values in patients undergoing non-invasive ventilation: a cohort study

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ABSTRACT

Background Blood gas analysis is important for assessment of ventilatory function. Traditionally, arterial analysis has been used. A method for mathematically arterialising venous blood gas values has been developed. Our aim was to validate this method in patients undergoing non-invasive ventilation (NIV) in an emergency department (ED).

Materials and methods This post hoc substudy of a prospective cohort study included adult patients undergoing NIV for acute respiratory compromise. When arterial blood gas analysis was required for clinical purposes, a venous sample was also drawn. Mathematically arterialised values were calculated independent of arterial values. Primary outcome of interest was agreement between mathematically arterialised venous and arterial values for pH and pCO_2. Bland-Altman agreement plot analysis was used.

Results Eighty sample-pairs (58 patients) were studied. Mean difference for arterial pH (actual-calculated) was 0.01 pH units (95% limits of agreement: −0.04, 0.06). Mean difference for pCO_2 (actual-calculated) was −0.06 kPa (95% limits of agreement: −1.34, 1.22).

Conclusions For patients undergoing NIV in an ED, agreement between mathematically arterialised venous values and arterial values was close for pH but only moderate for pCO_2. Depending on clinician tolerance for agreement, this method may be a clinically useful alternative to arterial blood gas analysis in the ED.

INTRODUCTION

In critical care settings, blood gas analysis is used for two main purposes: establishing acid-base state and assessing ventilation function. Assessment of ventilatory function using pCO_2, pH and pO_2 is particularly important for patients with severe respiratory compromise in order to assess the severity of ventilatory compromise and progression of illness or response to treatment. Oxygenation is now mainly measured by pulse oximetry, which has been shown to be accurate in this setting.[1] pH and pCO_2 are measured by blood gas analysis, historically performed on arterial blood; however, this is painful for patients, has rare but serious complications and, depending on the collection system used, poses a potential needlestick injury risk to staff.

Some authors have suggested that venous blood gas (VBG) analysis could replace arterial analyses, at least for selected conditions.[2–7] Current evidence suggests that arteriovenous agreement for pH is close and probably clinically interchangeable but data regarding pCO_2 are conflicting with some studies reporting close agreement and others unacceptably wide limits of agreement.[8–10] A method has been developed that can calculate arterial acid-base status from measurements in the peripheral venous blood combined with SpO_2 from a pulse oximeter: a 'mathematical arterialisation' method.[11] (figure 1) Validation studies in a number of settings have shown good agreement for the key parameters of pH, pCO_2 and pO_2.[12–15] Some of these studies was in patients with respiratory disorders,[12 15] but no subgroup of patients receiving non-invasive ventilation (NIV) was reported.

Patients undergoing NIV in emergency departments (ED) are a complex group. As well as acute respiratory distress, they may have serious underlying pathology that could impact their acid-base status (eg, sepsis) or be receiving pharmacotherapy that could alter skin perfusion, and thus, SpO_2 (eg, glyceryl trinitrate infusion). They may also display signs of adrenergic hyperactivity (eg, tachycardia), which also might impair skin perfusion. The mathematical arterialisation model has not been tested in these patients. Our aim was to validate this method in patients undergoing NIV in an ED.

METHODS

This was post-hoc substudy of a prospective observational study conducted in the ED of a community teaching hospital in Melbourne, Australia between March 2011 and June 2012. The study ED has an annual census of 36 000 patients.

The 'parent' study was designed to explored that agreement between arterial and venous pH and pCO2 in patients undergoing NIV.[16] Patients were eligible for inclusion in the study if they were undergoing NIV for acute respiratory distress in the ED and required arterial blood gas (ABG) analysis (as ordered by the treating physician) to assess their ventilatory function. In addition to the ABG sample, nursing staff were instructed to collect and analyse a VBG sample as close to simultaneously as possible. The vast majority of samples were drawn from arm veins via an in situ intravenous cannula. Up to three sample-pairs at two-hourly intervals could be collected per patient care episode if serial ABG were required for clinical care. Samples were excluded if results and timing could not be verified from the pathology results database or if there was more than 5 min between arterial and venous samples. In practice, this was a convenience sample as it relied on staff remembering to conduct the venous sampling and on clinical workload not precluding availability of time for the additional VBG analysis.

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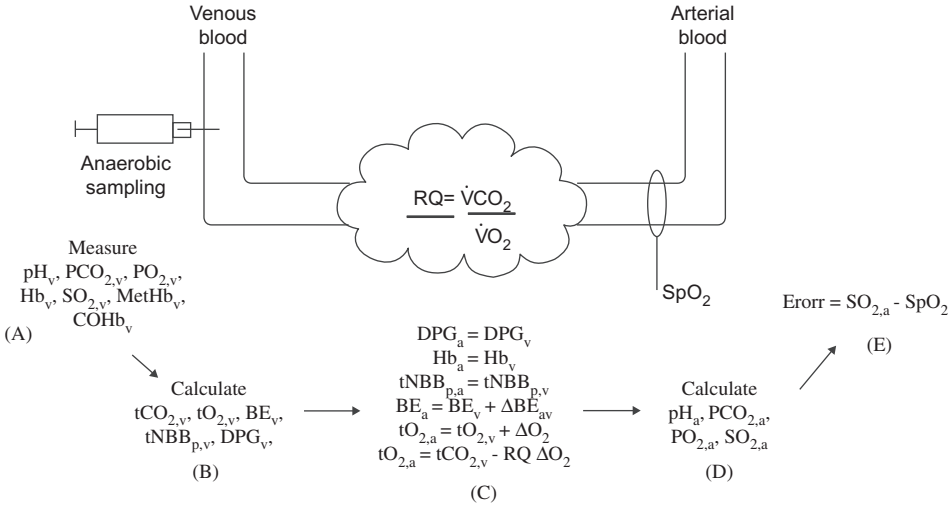

Figure 1 Diagram of mathematical arterialisation method.

Data collected included patient demographics (age and gender), clinical diagnosis, SpO_2 and results of blood analyses. Venous values were provided to SER who calculated the mathematically arterialised venous values independently and without access to arterial values.

During the study two blood gas analysers were in use. For the first part of the study period, a Radiopoint 405 analyser (Siemens Healthcare Diagnostics Inc. New York, USA) was used. This was replaced by a Radiometer ABL 825 (Radiometer Medical Aps, Denmark).

Primary outcome of interest was agreement between mathematically arterialised values and measured arterial values for pH and pCO_2 expressed as mean difference and 95% limits of agreement. Analysis was by Bland-Altman agreement plot techniques using Analyse-It software. No adjustment for repeated sampling was made.

As this was a post hoc analysis, no sample size calculation was made. In order to assess any impact of some patients providing more than one sample pair, a first sample per patient analysis was also performed.

This project was approved by the Western Health Low Risk Human Research Ethics Panel (HREC/11/WH/3). Patient consent was not required.

RESULTS

Eighty sample pairs in 58 patients were studied. Sample characteristics are shown in table 1. Mean difference for arterial pH (actual-calculated) was 0.01 pH units (95% limits of agreement −0.04, 0.06) (figure 2). Mean difference for pCO_2 (actual – calculated) was −0.06 kPa (95% limits of agreement −1.34, 1.22) (figure 3).

On first specimen/ patient analysis, mean difference for arterial pH (actual-calculated) was 0.009 pH units (95% limits of agreement −0.04, 0.06) and mean difference for pCO_2 (actual – calculated) was −0.03 kPa (95% −1.38, 1.32).

Mean arteriovenous difference (arterial – venous) was 0.03 pH units (95% limits of agreement −0.03, 0.11). Mean difference for pCO_2 (arterial – venous) was −1.06 kPa (95% limits of agreement −3.06, 0.93).

DISCUSSION

Evaluation of ventilatory function in patients with severe respiratory compromise is essential in order to ensure that management decisions are made promptly in response to changing clinical condition. A key component of this evaluation is blood gas analysis, principally looking at pCO_2 and pH. Previous research has suggested that arteriovenous agreement for pH is close with narrow 95% limits of agreement and that venous values are clinically interchangeable with arterial values.[8] Data regarding pCO_2 are less clear. Although a weighted average arteriovenous difference of 6.2 mm Hg (0.83 kPa) has been reported in a recent review, the width of the 95% limits of agreement were variable, with several of the studies reporting 95% limits of agreement of the order of ±20 mm Hg (~2.67 kPa).[8]

Another approach has been developed using VBG values and SpO_2 to derive arterial values. This has been called the mathematical arterialisation method. It has been validated in cohorts of intensive care unit, respiratory medicine and emergency medicine patients, showing good agreement with arterial values for pH and pCO_2.[12 15] Of particular relevance is the fact that a recent study of patients admitted to hospital with COPD showed that the mathematical arterialisation method performed significantly better than venous values alone.[12] Patients on NIV have not previously been studied. Their complex pathophysiology made it inappropriate to extrapolate the previously successful validations to this patient cohort.

Table 1 Sample characteristics

Characteristic	Result
Age (median, IQR)	73 (66–79)
Gender (N male, %)	38 (66%)
ED Diagnosis (N, %)	
COPD	35 (60.3%)
APO	20 (34.5%)
Other	3 (5.2%)
Pulse rate (median, IQR, range)	102; 86–116; 46–163
Respiratory rate (median, IQR, range)	24; 21–30; 14–45
MAP (median, IQR, range)	100; 91–113; 68–136
Oxygen saturation (%, median, IQR)	95 (92–100)
Hypoxic (SpO2≤93%, N, %)	31 (39%)
Acidosis (apH<7.35, N, %)	46 (56%)
Severe acidosis (apH≤7.2, N, %)	9 (11%)
Hypercarbia (paCO2>6.6 kPa, N, %)	39 (48%)
Haemoglobin (g/L; median, IQR)	135 (120–151)
Carboxyhaemoglobin (%, median, IQR)	1.3 (1.1–2.0)

ED, emergency department; MAP, mean arterial pressure.

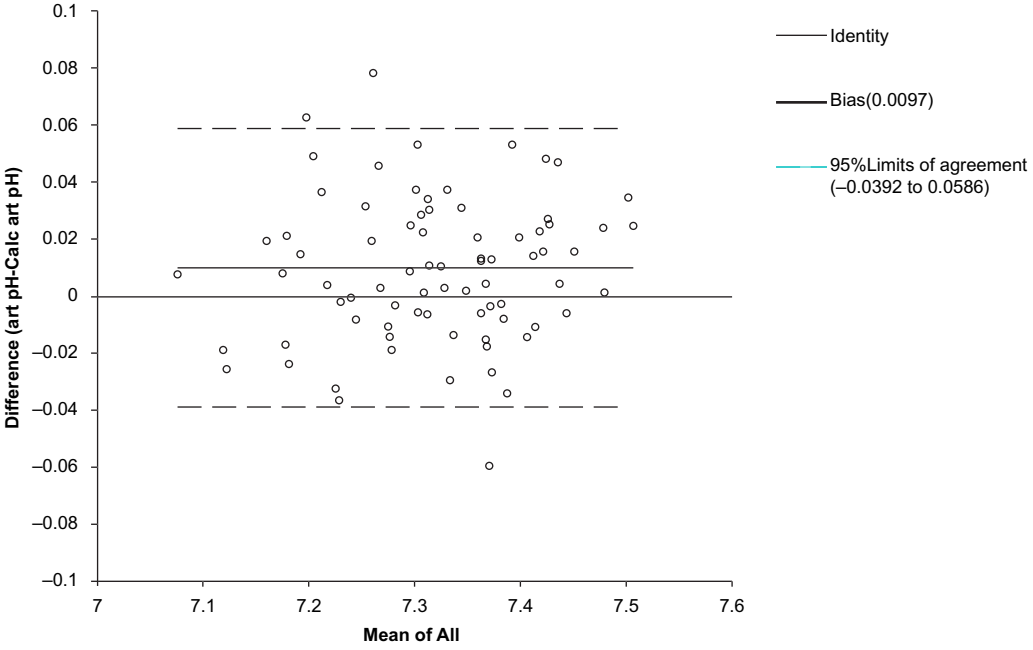

Figure 2 Agreement plot of agreement for pH.

We found that the mathematical arterialisation method performed better than arteriovenous agreement, especially for pCO_2. Mean difference for pH was smaller (0.01 pH units vs 0.04 pH units) with 95% limits of agreement that were slightly narrower. We also found a smaller average difference for pCO_2 (−0.05 kPa vs −1.07 kPa) with 95% limits of agreement that are much smaller than (about half) those for previously reported arteriovenous agreement and potentially within clinician tolerance.

When any two methods of measurement are being compared, it is important to define the clinically acceptable limits of agreement. In other words, how much difference between the two measurements can be tolerated by clinicians in clinical decision-making? This will vary between parameters and probably with clinical context. Unfortunately there are little data to inform these definitions. Rang *et al*,[17] in a survey of 26 clinicians, found that the clinically acceptable limits of agreement were 0.05 pH units and 6.6 mm Hg (~0.9 kPa) for pCO_2. An unpublished survey of 46 clinicians from Melbourne found clinically acceptable limits of agreement of 0.1 pH units. Further data from a large clinician group, preferably based on common clinical scenarios, are necessary before any definition of clinically acceptable differences can be proposed.

It is also important to remember that blood gas analysis is one piece of data guiding clinical decision-making, not the only piece. It is interpreted along with other vital signs (pulse rate, respiratory rate and oxygen saturation) and observed patient

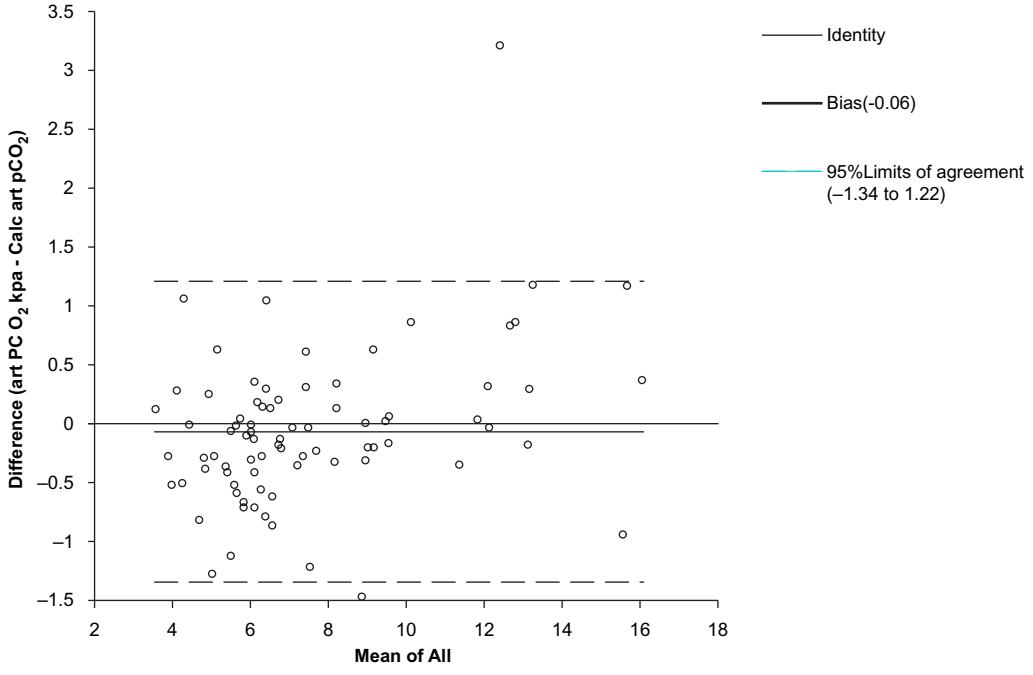

Figure 3 Agreement plot of agreement for pCO_2.

characteristics (eg, conscious state, work of breathing, evidence of tiring, ability to speak). When these data are integrated, tight numerical agreement for all blood gas parameters may not be as important as mismatches between clinical impression and blood gas data. This is another area worthy of more research.

Without a better understanding of clinician tolerance for agreement in relevant clinical scenarios and how non-ABG is integrated with clinical assessment, it is difficult to estimate the use of the mathematical arterialisations method in comparison to venous or arterial analyses.

This study has some limitations that should be considered when interpreting the results. While we attempted to collect a consecutive sample, the resulting sample was actually a convenience sample due to operational and resource limitations. We have no reason to suspect any systematic bias in selection. Treatment decisions were made independently by doctors not involved in the study, and so there may have been variation in the criteria used for initiation of NIV. This is a single site study and may not be generalisable to other settings or patient cohorts.

CONCLUSION

For patients undergoing NIV in an ED, agreement between mathematically arterialised venous values and arterial values was close for pH but only moderate for pCO_2. Depending on clinician tolerance regarding agreement, mathematically arterialised venous values may be a clinically useful alternative to ABG analysis in the ED.

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Contributors AMK and SER had the concept for the study, AMK and SK designed the study, SK oversaw data collection and management, AMK and SER analysed data, AMK and SER interpreted data, AMK drafted the manuscript and SER and SK participated in manuscript revision.

Competing interests This research was supported by departmental funds only. Prof Rees is a shareholder and board member of OBI Aps who own a patent on the mathematical arterialisation method. Prof Kelly and Mrs. Klim have no conflicts of interest to declare.

Ethics approval Western Health Low Risk Ethics Panel.

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