



Mathematical arterialisation of peripheral venous blood gas for obtainment of arterial blood gas values: a methodological validation study in the clinical setting

Mads Lumholdt^{1,2,3,5} · Kjeld Asbjørn Damgaard¹ · Erika Frischknecht Christensen⁴ · Peter Derek Christian Leutscher^{2,3}

Received: 28 April 2018 / Accepted: 4 September 2018 / Published online: 8 September 2018
© Springer Nature B.V. 2018

Abstract

Arterial blood gas (ABG) analysis is an essential tool in the clinical assessment of acutely ill patients. Venous to arterial conversion (v-TAC), a mathematical method, has been developed recently to convert peripheral venous blood gas (VBG) values to arterialized VBG (aVBG) values. The aim of this study was to test the validity of aVBG compared to ABG in an emergency department (ED) setting. Twenty ED patients were included in this study. ABG and three aVBG samples were collected from each patient. The aVBG samples were processed in three different ways to investigate appropriate sample handling. All VBG samples were arterialized using the v-TAC method. ABG and aVBG samples were compared using Lin's concordance correlation coefficient (CCC), Bland–Altman plots and misclassification analysis. Clinical acceptable threshold of aVBG value deviance from ABG values were ± 0.05 pH units, ± 0.88 kPa pCO₂ and ± 0.88 kPa pO₂. CCC revealed an agreement in pH and pCO₂ parameters for both aVBG in comparison to ABG. In all aVBG samples, an overestimation of pO₂ compared to ABG was observed. Bland–Altman plot revealed clinically acceptable mean difference and limits-of-agreement intervals between ABG and aVBG pH and pCO₂, but not between ABG and aVBG pO₂. Arterialization of VBG using v-TAC is a valid method for measuring pH and pCO₂, but not for pO₂. Larger clinical studies are required to evaluate the applicability of v-TAC in different patient subpopulations.

Keywords Arterial blood gas analysis · Emergency service, hospital · Venous to arterial conversion · Matched-pair analysis

1 Introduction

Arterial blood gas (ABG) analysis is essential in assessment of respiratory and metabolic status in acutely ill patients. In comparison to peripheral venous blood sampling, the ABG

sampling procedure is more painful for the patient and technically more challenging for the clinician to perform [1, 2]. Other drawbacks of ABG sampling include adverse events such as subcutaneous hematoma, arterial thrombosis, and the serious, though rare, complication pseudoaneurysms [3, 4].

Peripheral venous blood gas (VBG) sampling has been suggested as an alternative to the ABG procedure. This procedure causes less patient discomfort and the sample can be analysed in combination with other venous blood tests [5]. A recent systematic review comparing ABG and VBG in the emergency department (ED) have revealed that pH and bicarbonate show reasonable agreement with mean difference -0.033 pH units and 1.03 mmol/l bicarbonate, respectively. Limits-of-agreement was -0.13 to 0.10 for pH and -6.24 mmol/l to 10.00 mmol/l for bicarbonate. pCO₂ showed mean difference of 4.41 mmHg and wide limits-of-agreement of -20.40 to 25.8 mmHg. Authors concluded that

✉ Mads Lumholdt
m.lumholdt@rn.dk

¹ Department of Anaesthesiology, North Denmark Regional Hospital, Bispensgade 37, 9800 Hjørring, Denmark

² Centre for Clinical Research, North Denmark Regional Hospital, Bispensgade 37, 9800 Hjørring, Denmark

³ Clinical Institute, Aalborg University, Søndre Skovvej 11, 9000 Aalborg, Denmark

⁴ Centre for Prehospital and Emergency Research, Clinical Institute, Aalborg University, Søndre Skovvej 11, 9000 Aalborg, Denmark

⁵ Hals, Denmark

venous and arterial pH and bicarbonate agree acceptable, but arteriovenous agreement of $p\text{CO}_2$ was poor [6].

However, a new method has been developed to calculate ABG values mathematically from peripheral venous blood by use of venous to arterial conversion (v-TAC) software (Obimedical, Denmark), supplemented with oxygen saturation measurement by pulse oximetry [7]. The principle of the method is a mathematical transformation of VBG values to arterialized values (aVBG) by simulating the transport of blood back through the tissue. The authors made assumptions; Firstly, the peripheral limb must be well perfused with normal capillary response and temperature. Secondly, the respiratory quotient [RQ, i.e. rate of CO_2 production (VCO_2) and O_2 utilisation (VO_2)] must not vary beyond the range of 0.7–1.0.

Earlier testing of the v-TAC method in an ED setting has shown acceptable congruence levels between arterial and mathematically arterialized pH and $p\text{CO}_2$ with only minor differences ($\pm 2 \times \text{SD}$) – 0.001 (± 0.024) and 0.00 (± 0.46) kPa, respectively. However, inaccurate values of $p\text{O}_2$ were observed when oxygen saturation measured by pulse oximetry was above 96%, due to the flat shape of the oxygen dissociation curve (ODC) at higher oxygen saturation [8].

The aim of this study was to evaluate the validity of the v-TAC method in an acute medical emergency setting and test appropriate practical handling of VBG samples.

2 Methods

2.1 Patient inclusion

The study was conducted in the ED at the North Denmark Regional Hospital from September through October 2015. Circulatory stable patients needing ABG analysis for clinical respiratory and metabolic assessment were selected randomly for participation in the study. A total of 30 adult patients were included; 10 patients for a methodological pre-study and then 20 patients for the following validation study and test of different blood samples procedures. Allocation was performed by simple quasi-random algorithm in order of admission. The clinical decision for performance of ABG analysis was made on discretion by the attending physician in the ED upon patient admission and based on national guidelines [9].

2.2 Blood collection

All VBG samples were collected by a biomedical laboratory technician in conjunction with routine venous blood sampling in the methodological pre-study. VBG was collected in the 4.5 ml tube as opposed to the arterial blood 2.0 ml syringe as a three-way stopcock would have to be coupled

with the venous blood sampling kits, but we found this inconvenient in our hospital setting. Furthermore, biomedical laboratory technicians were at risk of accidental needle injury if a syringe was coupled directly over the sampling kit needle. For that reason, we conducted this methodological pre-study to compare VBG samples in paired 2.0 ml and ABG syringes.

2.3 Blood sample handling

In the validation study paired ABG and VBG samples were collected simultaneously from each of the 20 patients. Blood for VBG analysis was collected by the laboratory technician in three 4.5 ml tubes and converted to arterialised VBG (referred to as aVBG). ABG samples were collected by the attending physician. Each aVBG tube was processed differently as follows: aVBG₁ was held steady and analysed within 5 min of sample collection, aVBG₂ was tilted in 5 min and analysed after 7 min and aVBG₃ was handled as aVBG₁ but analysed after 15 min. ABG samples were analysed within 5 min after sampling.

2.4 Blood analysis

All ABG and VBG samples were analysed with ABL800 blood gas analyser (Radiometer, Denmark) an VBG samples were converted mathematically to aVBG using v-TAC software integrated into the ABL800. Figure 1 show calculations of the v-TAC simulation in five steps (A–E) [7]. On the standard of care basis, only the ABG results were used as the usual standard reference in the medical evaluation of the patients. Normal reference ranges of study variables were as follows pH, 7.35–7.45, $p\text{CO}_2$, 4.26–6.38 kPa and $p\text{O}_2$, 10.6–13.3 kPa, respectively [10].

2.5 Threshold values

In this present study, clinically acceptable thresholds between ABG and aVBG values were determined as ± 0.05 for pH, and ± 0.88 kPa for both $p\text{CO}_2$ and $p\text{O}_2$. Consequently, clinically acceptable intervals of calculated arterial values were determined to be 0.1 pH units and 1.76 kPa for both $p\text{CO}_2$ and $p\text{O}_2$ compared to ABG values. Acceptable rate of misclassification was set to 5% as in a similar study [11]. Extreme-to-extreme misclassification was not allowed.

2.6 Sample size

A previous study on the v-TAC method reported mean difference ($\pm 2 \times \text{SD}$) of -0.001 ± 0.024 and -0.00 ± 0.46 kPa between calculated arterial and ABG pH and $p\text{CO}_2$, respectively [8]. With the predetermined clinical acceptable threshold of calculated arterial pH ± 0.05 and $p\text{CO}_2 \pm 0.88$ kPa,

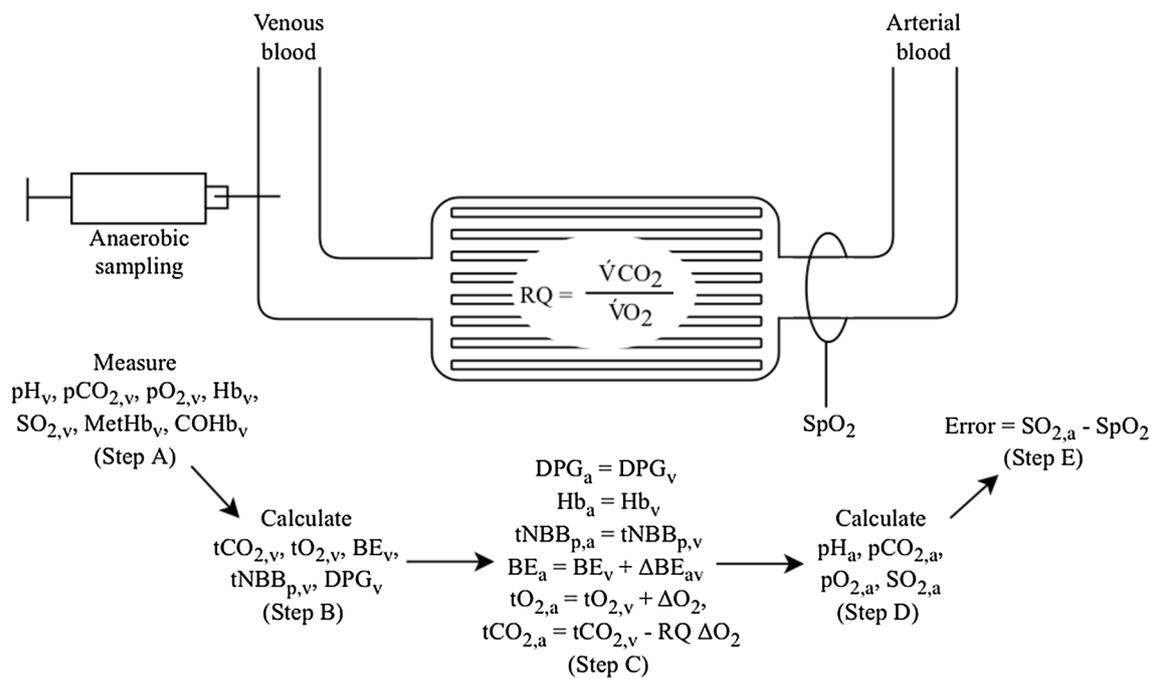


Fig. 1 Calculation of arterial acid–base and oxygen values from VBG using v-TAC. Step A an anaerobic venous blood sample is collected and $pH_v, pCO_{2,v}, SO_{2,v}, pO_{2,v}$, haemoglobin (Hb_v), methaemoglobin (MetHb_v), and carboxyhaemoglobin (COHb_v) are measured. Step B measured values are used to calculate total CO_2 concentration ($tCO_{2,v}$), total O_2 concentration ($tO_{2,v}$) and 2,3-diphosphoglycerate concentration (DPG_v) in venous blood. Base excess is estimated independently of O_2 levels by calculating the total concentration of plasma non-bicarbonate buffer ($tNBB_{p,v}$) and combining the concentration with pH_v . Step C variables $tCO_{2,v}, tO_{2,v}, Hb_v, BE_v, DPG_v$ and $tNBB_{p,v}$ are used to estimate the respective variables in arterial blood. It is assumed that $Hb, tNBB_p$ and DPG concentrations are the same in arterial and venous blood. Calculations of arterial O_2 and CO_2 is

then performed by simulating addition of a difference in O_2 concentration (ΔO_2), to the venous pO_2 measurement and removing a difference in concentration of CO_2 (ΔCO_2) from pCO_2 in the venous blood. Step D calculated values of arterialised blood $tCO_{2,a}, tO_{2,a}, Hb_v, BE_a, tNBB_{p,a}$ and DPG_a are used to estimate $pH_a, pCO_{2,a}, pO_{2,a}$ and $SO_{2,a}$. Step E calculated $SO_{2,a}$ is compared with measured pulse oximeter (SpO_2), the difference between the two gives an error = $SO_{2,a} - SpO_2$. By repeating steps C–E, a value of ΔO_2 is found for which the error is zero. Multiplying the respiratory quotient with ΔO_2 the concentration of CO_2 removed is calculated. Thus calculated values of $pH_a, pCO_{2,a}, pO_{2,a}$ and $SO_{2,a}$ should be equal to measured arterial values. Reproduced with permission from publisher [7]

the requires study sample size (alpha level 0.005 and 80% power) was estimated to 11 paired samples with pH as reference and 14 paired samples with pCO_2 as reference using MedCalc v18.6 (MedCalc Software bvba) sample size calculator for agreement studies. If power was increased to 90%, 13 and 16 paired samples, respectively, were sufficient using pH and pCO_2 as reference. Because, SD of pO_2 was missing in the study [8], a sufficient sample size could, therefore, not be calculated with pO_2 as reference.

2.7 Statistics

Assessment of agreement between sample collection methods, and between ABG and aVBG values, were conducted using Bland–Altman’s analysis, Pearson’s correlation coefficient (PCC), and Lin’s concordance correlation coefficient (CCC). Strength of agreement was assessed by calculating tolerability interval ratio, which is the actual

limits-of-agreement interval in this study expressed as the proportion of the clinically acceptable interval [12]. Additionally, rate of misclassification and rate of extreme-to-extreme misclassification is calculated for individual sample pairs with ABG values as gold standard [12]. Statistical analysis was conducted using Stata 13 SE (Stata Corp, College Station).

2.8 Ethics and data protection

This study was approved by the Danish Data Protection Agency. The Danish Research Ethics Committee in the North Denmark Region was notified about the study. Since the v-TAC method has previously been approved in clinical research and blood sampling was performed as routine practice based on clinical indication, ethical approval was not required.

3 Results

3.1 Methodological pre-study

Median age of the ten patients in the methodological pre-study was 56 years (range 26–86). Comparison of paired VBG samples collected in 2 ml syringes and 4.5 ml tubes displayed close correlation with mean difference (SD) of pH and pCO₂ was on 0.01 (0.01) pH units and –0.02 (0.27) kPa, respectively, and CCC values was 0.925 and 0.943 (Table 1). However, pO₂ displayed poor agreement between the two sampling containers with a mean difference (SD) pO₂ value of –0.57 (1.10) kPa and CCC value on 0.660 because mean pO₂ (SD) was higher in the tube, 4.74 (1.66) kPa, compared to the syringe, 4.18 (1.22) kPa.

3.2 The validation study

Median age of the 20 patients was 66 years (range 36–96 years). All patients were circulatory stable and none suffered from severe respiratory failure. Patient characteristics are presented in Table 2. Comparison analysis between ABG and aVBG samples are summarised in Table 3. The CCC displayed good agreement between pH and pCO₂ in all comparison of ABG and aVBG, except between ABG and aVBG₂ pCO₂, where a CCC value of 0.639 displayed weak agreement. Overestimation of pO₂ in aVBG samples resulted in a higher mean difference (SD) –0.97 (1.32) kPa, –1.25 (1.73) kPa and –1.00 (1.34) kPa in the three aVBG samples compared to ABG. Therefore, CCC analysis displayed poor agreement values of 0.720, 0.652 and 0.716 between ABG and aVBG₁₊₂₊₃ pO₂.

3.3 Bland and Altman analysis

Bland and Altman plots are presented in Fig. 2. The Bland–Altman findings were in accordance with the CCC findings in the validation study. Mean pH difference between ABG and aVBG₁ and between ABG and aVBG₃ was within predefined threshold values. Mean difference between all aVBG₂ pH samples and ABG pH samples was within acceptable threshold range. Similar tendencies were

Table 2 Characteristics of patients in the validation study

Patient parameters	<i>n</i> (%)
Age (year)	
≤ 64	5 (25)
65–74	6 (30)
≥ 75	9 (45)
Sex	
Female	8 (40)
Male	12 (60)
Cause of admission	
COPD exacerbation	6 (30)
Pneumonia	3 (15)
Suspected abdominal ischemia	3 (15)
Dehydration	3 (15)
Cor pulmonale	2 (10)
Diabetic ketoacidosis	1 (5)
Dysregulated diabetes mellitus	1 (5)
Bleeding haemorrhoid	1 (5)
Comorbidities	
COPD	8 (40)
Heart failure	5 (25)
Essential hypertension	4 (20)
IHD	2 (10)
Arterial fibrillation	2 (10)
Diabetes mellitus	2 (10)
Myxoedema	1 (5)
Small cell carcinoma	1 (5)

Patient characteristics and comorbidities in the validation study

COPD chronic obstructive pulmonary disease, *IHD* ischemic heart disease

observed when comparing pCO₂ results. Mean difference in pCO₂ was within predefined acceptable threshold range in overall comparison between all ABG and aVBG pCO₂ values (Table 2), but at an individual patient level, three aVBG₂ pCO₂ samples were above threshold values, hence rate of misclassification was 15%. Mean difference of pO₂ between ABG and all aVBG samples was unacceptably above predefined thresholds regardless of sample handling procedure. This was caused by overestimation of pO₂ in a

Table 1 Comparison of blood gas sampling in 2 ml ABG syringe and 4.5 ml tube in the pre-study patients (*n* = 10)

Parameters	ABG syringe Mean (SD)	Tube Mean (SD)	Mean difference (SD)	Concordance correlation analysis			
				CCC	95% CI	<i>r</i>	<i>Cb</i>
pH	7.39 (0.04)	7.39 (0.03)	0.01 (0.01)	0.925	0.838–1.013	0.949	0.975
pCO ₂ (kPa)	5.90 (0.82)	5.91 (0.75)	–0.02 (0.27)	0.943	0.869–1.017	0.947	0.996
pO ₂ (kPa)	4.18 (1.22)	4.74 (1.66)	–0.57 (1.10)	0.660	0.326–0.994	0.750	0.880

Comparison of sample containers in group A: CCC Lin's concordance correlation coefficient, 95% CI 95% confidence interval of CCC, *r* Pearson's correlation coefficient, *Cb* bias-correction factor, *kPa* kilopascal

Table 3 Comparison of ABG and arterialized VBG values in the validation study patients ($n = 20$)

Parameters	ABG Mean (SD)	aVBG Mean (SD)	Mean difference (SD)	Concordance correlation analysis			
				CCC	95% CI	r	Cb
pH	7.42 (0.05)	7.42 (0.05) ^a	0.00 (0.02) ^a	0.939 ^a	0.885–0.994 ^a	0.941 ^a	0.998 ^a
		7.39 (0.04) ^b	0.03 (0.02) ^b	0.744 ^b	0.590–0.899 ^b	0.918 ^b	0.811 ^b
		7.42 (0.05) ^c	0.00 (0.02) ^c	0.942 ^c	0.891–0.994 ^c	0.942 ^c	1.000 ^c
pCO ₂ (kPa)	4.94 (0.62)	4.98 (0.61) ^a	−0.05 (0.22) ^a	0.935 ^a	0.878–0.993 ^a	0.938 ^a	0.997 ^a
		5.48 (0.61) ^b	−0.54 (0.28) ^b	0.639 ^b	0.453–0.825 ^b	0.895 ^b	0.714 ^b
		4.95 (0.60) ^c	−0.01 (0.24) ^c	0.923 ^c	0.856–0.991 ^c	0.924 ^c	0.999 ^c
pO ₂ (kPa)	10.28 (1.76)	11.24 (2.38) ^a	−0.97 (1.32) ^a	0.720 ^a	0.539–0.902 ^a	0.837 ^a	0.861 ^a
		11.53 (2.92) ^b	−1.25 (1.73) ^b	0.652 ^b	0.467–0.838 ^b	0.841 ^b	0.775 ^b
		11.27 (2.41) ^c	−1.00 (1.34) ^c	0.716 ^c	0.534–0.898 ^c	0.839 ^c	0.854 ^c

Comparison analysis of ABG and aVBG in group B

ABG arterial blood gas, aVBG arterIALIZED venous blood gas, CCC Lin's concordance correlation coefficient, 95% CI 95% confidence interval of CCC, r Pearson's correlation coefficient, Cb bias-correction factor, kPa kilopascal

^aaVBG analysed within 5 min after sampling

^baVBG tilted in 5 min and analysed after 7 min

^caVBG held steady and analysed after 15 min

majority of the aVBG₁ ($n = 12$), aVBG₂ ($n = 12$) and aVBG₃ ($n = 11$) samples.

25% (5/20) between ABG and aVBG₁₊₂₊₃ pO₂ values, respectively.

3.4 Tolerability interval ratio

The strength of limits-of-agreement expressed as the tolerability interval ratio was 0.65, 0.77 and 0.64, respectively, in pH between ABG and all three aVBG₁₊₂₊₃ samples. Being less than one in each single comparison, it can be concluded that the limits-of-agreement interval is sufficiently narrow for pH as to assure correct assessment of patients' blood gas values when using v-TAC. Likewise, tolerability interval ratio in pCO₂ between ABG and all three aVBG₁₊₂₊₃ samples was 0.48, 0.63 and 0.53. However, tolerability interval ratios for pO₂ agreement was 2.94, 3.84 and 2.97 between ABG and aVBG₁, ABG and aVBG₂ and ABG and aVBG₃, respectively, which is above two and therefore unacceptable.

3.5 Misclassification

Rate of misclassification was zero comparing pH in the aVBG₁ and ABG, and aVBG₃ and ABG sample pairs. The aVBG₂ versus ABG pH rate of misclassification was 10% (2/20). Similar tendencies were observed comparing pCO₂, with aVBG₁ versus ABG, and aVBG₃ versus ABG rate of misclassification of zero, but 15% (3/20) in aVBG₂ versus ABG pCO₂. Rate of misclassification was 60% (12/20), 60% (12/20) and 55% (11/20) between ABG versus aVBG₁₊₂₊₃ pO₂, respectively.

No extreme-to-extreme misclassification occurred comparing aVBG versus ABG in pH and pCO₂. Extreme-to-extreme misclassification was 25% (5/20), 25% (5/20) and

4 Discussion

This study has shown that the v-TAC method delivers clinically valid information on pH and pCO₂ in patients admitted to the ED. Bland and Altman differences were within predefined clinical acceptable threshold ranges for pH and pCO₂ between ABG and aVBG sample pairs. Analogously, tolerability interval ratios were below one between all ABG and aVBG comparison in the parameters pH and pCO₂, hence it can be concluded that the limits-of-agreement interval was sufficiently narrow for the two parameters in all aVBG and ABG sample pairs as to assure correct assessment and treatment of patients when using v-TAC in daily clinical practice. Difference between ABG and calculated aVBG pO₂, however, was outside predefined threshold ranges in all sampled pairs. Moreover, tolerability interval ratio showed unacceptable broad limits-of-agreement and a rate of extreme-to-extreme misclassifications as high as 25%. Reliable acid–base and blood gas values are important for correct patient treatment in the ED setting, thus extreme-to-extreme misclassification was not allowed. Extreme-to-extreme misclassification could result in undertreatment of patients with severely abnormal acid–base or blood gas values.

As also observed in this study, research team behind the v-TAC method found high levels of pO₂ in aVBG samples compared to ABG, but argued that the poor agreement is due to the flat shape of the ODC close to 100% blood oxygen saturation level [7]. Even minor changes in blood O₂

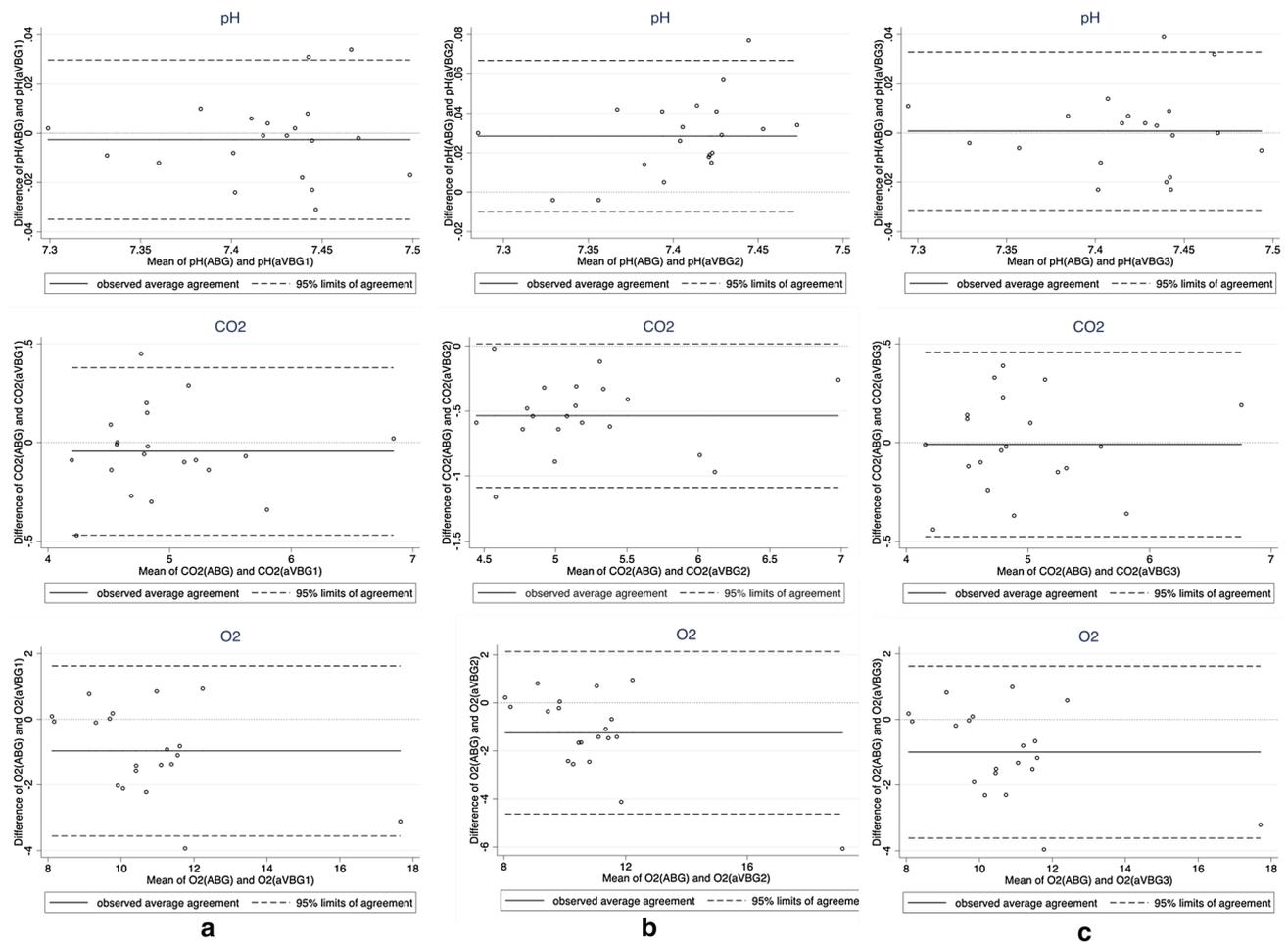


Fig. 2 Bland and Altman plots of ABG and aVBG value agreement in the validation study. **a** ABG and aVBG₁; **b** ABG and aVBG₂; **c** ABG and aVBG₃. *ABG* arterial blood gas, *aVBG* arterialized venous blood gas, *CCC* Lin's concordance correlation coefficient, *95% CI*

95% confidence interval of CCC, *r* Pearson's correlation coefficient, *C_b* bias-correction factor. aVBG₁ analysed within 5 min after sampling. aVBG₂ tilted in 5 min and analysed after 7 min. aVBG₃ held steady and analysed after 15 min

saturation may affect calculated pO_2 pressure significantly when saturation is above 96%. At low O_2 saturation calculating pO_2 should be more accurate due to the steepness of the ODC at O_2 saturation. The same principle applies to the ABG analysis regarding the difference between ABG and aVBG pO_2 values [13]. The selected sample collection tube in the study may also explain the overestimated pO_2 values. In the methodological pre-study mean venous pO_2 was 0.57 kPa higher in the 4.5 ml tube compared with the syringe. Furthermore, the correlation between containers was poor. Higher oxygen values could have been caused by oxygen bubbles in the venous blood sampling kit, which have been sucked into the tube and then absorbed by the venous blood. Leftover oxygen in the vacuum of the tubes could also explain this difference. Hence, the observed overestimation of calculated aVBG pO_2 in the validation study could very well be related to an inappropriate choice of sample container, and the reliability of v-TAC

pO_2 should be investigated further in different sample containers, before its use is ruled out in the ED setting.

It was surprising that the v-TAC method managed to calculate pCO_2 with both accuracy and precision, as established previously, the method relies on calculated arteriovenous difference in O_2 to calculate pCO_2 values (step E in Fig. 1). Since calculated pO_2 is generally overestimated and limits-of-agreement was observed at an unacceptable level in this study, the accuracy of the difference in O_2 may not be of major importance in the overall calculation.

Tilting of VBG₂ samples collected in 4.5 ml tubes caused an increase of pCO_2 and lowered pH, which resulted in misclassification rate of aVBG₂ pCO_2 just above the predefined 5% threshold. Although a larger sample size might lower the misclassification rate for calculated pCO_2 , careful sample handling should be advised to obtain valid estimations of pCO_2 .

McCanny et al. reject VBG as a reliable alternative to ABG due to variations in venous pCO₂ agreement with arterial pCO₂ [14]. Bland and Altman's plot demonstrated average difference in 8.6 mmHg (1.15 kPa) and limits of agreement from -7.84 mmHg (-1.02 kPa) to 25.05 mmHg (3.34 kPa) between venous and arterial pCO₂ [14]. Although only 20 patients were included in the present study clinically acceptable difference and narrow limits-of-agreement of pCO₂ between aVBG and ABG were observed. Therefore, the v-TAC could contribute to make for a more precise estimation of arterial pCO₂.

Clinically acceptable ranges of difference between ABG and aVBG is challenging to determining. Either, normal reference ranges are used as tolerable intervals [12], or alternatively acceptable laboratory intervals are calculated ($\pm 2 \times SD$) [15]. In questionnaire-based survey certified ED physicians reported maximum figures they would feel comfortable about regarding differences between monitored arterial and calculated arterial values for pH and pCO₂ in clinical practice. The results were as follows: mean (95% CI) 0.05 (0.04–0.06) for pH and 0.88 (0.74–1.01) kPa for pCO₂ [16]. These acceptable thresholds were used in this present study. Values for pO₂ were not covered in the survey.

According to the research team behind the v-TAC method, the peripheral limb has to be well perfused and the respiratory quotient has to be within 0.7 and 1.0 for v-TAC to deliver accurate estimates of ABG [7]. In this present study all included patients were circulatory stable and no one suffered from severe respiratory failure. However, in the critically ill patient, both the respiratory quotient and peripheral blood perfusion may vary considerably, depending on the underlying pathophysiological mechanisms [17, 18]. The v-TAC method may not be appropriate to assess patients with extreme conditions, but it may be able to identify potential critically ill patients with extreme acid–base status or blood gas values in a mixed ED patient population.

Our study has a number of limitations. It was designed as a single-centre study with a small number of participants without specific clinical characteristics. Hence, in this heterogeneous study group results could not be generalised. Moreover, randomisation was performed by a simple quasi-random allocation and the study results suggest that anaerobic sampling might not have been guaranteed in the 4.5 ml tube even if air bubbles in the venous blood sampling kit was avoided.

In medical departments where repeated blood gas is required (e.g. in patients with COPD), the v-TAC method may reduce the need for repeated painful arterial punctures, since sampling of blood gas is achieved in conjunction with routine venous blood sampling. The reliability and utility of method should be examined in large studies, preferably multicentre studies, which renders subdivision of patients into groups according to cause of admission, severity of

symptoms or conditions (e.g. hypoxia, hypo- or hypercapnia, severe acidosis or severe anaemia) in order to clarify under which conditions this method is reliable.

5 Conclusion

Mathematical arterialisation of VBG was found to be a valid method for calculation of pH and pCO₂ ABG values in circulatory stable ED patients, whereas the arterialised values of pO₂ showed overestimation and clinically unacceptable broad limits-of-agreement. This observation could be due to the venous blood sampling procedure in which 4.5 ml tubes were used. The usability of v-TAC in critically ill patients with reduced peripheral blood perfusion or extreme acid–base or blood gas values remains to be explored in future studies.

Compliance with ethical standards

Conflict of interest None declared from all authors.

References

1. Dar K, Williams T, Aitken R, Woods KL, Fletcher S. Arterial versus capillary sampling for analysing blood gas pressures. *BMJ Br Med J.* 1995;310:24–5.
2. Matheson L, Stephenson M, Huber B. Reducing pain associated with arterial punctures for blood gas analysis. *Pain Manag Nurs.* 2014;15:619–24. <https://doi.org/10.1016/j.pmn.2013.06.001>.
3. Leone V, Misuri D, Console N. Radial artery pseudoaneurysm after a single arterial puncture for blood-gas analysis: a case report. *Cases J.* 2009;2:6890. <https://doi.org/10.4076/1757-1626-2-6890>.
4. Dev SP, Hillmer MD, Ferri M. Arterial puncture for blood gas analysis. *N Engl J Med.* 2011;364:e7. <https://doi.org/10.1056/NEJMc0803851>.
5. 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.* 2006;210:285–90. <https://doi.org/10.1620/tjem.210.285>.
6. Bloom BM, Grundlingh J, Bestwick JP, Harris T. The role of venous blood gas in the emergency department: a systematic review and meta-analysis. *Eur J Emerg Med.* 2014;21:81–8. <https://doi.org/10.1097/MEJ.0b013e32836437cf>.
7. Rees SE, Toftegaard M, Andreassen S. A method for calculation of arterial acid-base and blood gas status from measurements in the peripheral venous blood. *Comput Methods Programs Biomed.* 2006;81:18–25. <https://doi.org/10.1016/j.teln.2006.04.001>.
8. Tygesen G, Matzen H, Grønkjær K, Uhrenfeldt L, Andreassen S, Gaardboe O, Rees SE. Mathematical arterialization of venous blood in emergency medicine patients. *Eur J Emerg Med.* 2012;19:363–72. <https://doi.org/10.1097/MEJ.0b013e32834de4c6>.
9. Foss NB, Hansen-Nord G. Arteriepunktur. In: *Lægehåndbogen.* 2016. <https://www.sundhed.dk/sundhedsfaglig/laegehaandbogen/undersogelser-og-proever/kliniske-procedurer/hjertekar/arteriepunktur/>. Accessed 1 Jan 2017.

10. Seeger C, Higgins C. Acute care testing—handbook. In: Radiom. Med. ApS, Denmark. 2014. <https://www.radiometer.com/~media/radiometer/corporate/files/campaigns/handbook/acutecaretestinghandbookpdfversion.pdf?la=en>. Accessed 1 Sept 2018.
11. Boulain T, Garot D, Vignon P, Lascarrou J-B, Benzekri-Lefevre D, Dequin P-F. Predicting arterial blood gas and lactate from central venous blood analysis in critically ill patients: a multicentre, prospective, diagnostic accuracy study. *Br J Anaesth*. 2016. <https://doi.org/10.1093/bja/aew261>.
12. Columb MO. Clinical measurement and assessing agreement. *Curr Anaesth Crit Care*. 2008. <https://doi.org/10.1016/j.cacc.2008.07.001>.
13. Collins JA, Rudenski A, Gibson J, Howard L, O'Driscoll R. Relating oxygen partial pressure, saturation and content: the haemoglobin–oxygen dissociation curve. *Breathe* 2015;11:194–201.
14. McCanny 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. <https://doi.org/10.1016/j.ajem.2011.06.011>.
15. Clinical Laboratory Improvement. Amendment (CLIA) of 1988. 7002–7288.
16. Rang LCF, Murray HE, Wells GA, Macgougan CK. Can peripheral venous blood gases replace arterial blood gases in emergency department patients? *CJEM Can J Emerg Med Care = JCMU J Can Soins Médicaux D'urgence*. 2002. <https://doi.org/10.1017/S1481803500006011>.
17. Castagneto M, Giovannini I, Boldrini G. Cardiorespiratory and metabolic adequacy and their relation to survival in sepsis. *Circ Shock*. 1983;11:113–30.
18. Lauscher P, Lauscher S, Kertscho H, Habler O, Meier J. Hyperoxia reversibly alters oxygen consumption and metabolism. *Sci World J*. 2012;2012:410321. <https://doi.org/10.1100/2012/410321>.