Arterial blood gas analysers: accuracy in determining haemoglobin, glucose and electrolyte concentrations in critically ill adult patients

L. M. QUINN*, N. HAMNETT†, R. WILKIN† and A. SHEIKH*
*Department of General Surgery, Warrington and Halton Hospitals NHS Trust, Warrington; and †Department of General Surgery, Royal Liverpool University Hospital, Liverpool, UK

Accepted: 20 June 2013

ABSTRACT

Arterial blood gas (ABG) machines are vital tools in the assessment of critically ill patients. Current ABG point-of-care (POC) analysers provide information on concentrations of haemoglobin, glucose and electrolytes in addition to acid-base balance. Awaiting results from venous analysers may present a significant delay in diagnosis and management, thus reliance on arterial blood gas determination of these parameters is increasing. However, published data on the concordance between the two modalities are limited. This study aims to assess the concordance of ABG machines in analysing haemoglobin, glucose and electrolyte concentrations compared to standard venous analysers as the gold standard. Results from 100 patients undergoing ABG analysis and simultaneous venous sampling without therapeutic intervention between sampling were compared. Differences in haemoglobin, glucose, sodium and potassium concentrations were determined and analysed using statistical software (Statview). There was a significant difference ($P<0.02$, paired signed test) in the mean haemoglobin concentration between the two modalities of 0.91 g/dL (range: 0–4.3 g/dL). Mean discrepancy in glucose concentrations was 1.16 mmol/L (range: 0–10.5 mmol/L; $P<0.012$, paired-signed test). Sodium and potassium showed no significant difference within the physiological range. At higher concentrations of potassium (>5 mmol/L), ABG readings varied significantly ($P<0.0013$, paired sign test) from standard venous estimates (mean difference: 0.44 mmol/L). Arterial blood gas analysers are invaluable for rapid assessment of critically ill patients; however, estimations of haemoglobin, glucose and potassium concentrations (>5 mmol/L) obtained from such machines should be interpreted with caution and confirmed using standard venous samples.

KEY WORDS: Blood chemical analysis.
Hemoglobin.
Glucose.
Potassium.
Sodium.

Introduction

Arterial blood gas (ABG) analysers normally measure the oxygen and carbon dioxide partial pressures and acid base balance in arterial blood. The role in the assessment and monitoring of critically ill patients is well established, acting as a vital tool in the emergency department, operating theatre and on the intensive care unit.[1,2]

Current ABG analysers at the point of care also offer estimation of haemoglobin, glucose, sodium and potassium concentrations, and these are deemed comparable to venous results according to manufacturer specifications. Rapid knowledge of these parameters is invaluable when provided by the ABG machine, and may dictate initial management of a wide spectrum of conditions until definitive laboratory venous sample analysis is available.[3] Awaiting such venous laboratory results at times presents a significant delay in the management of the critically unwell and thus reliance on the data provided by ABG analysers on these parameters is increasing.[4]

Data on the accuracy of ABG analysers in assessing haemoglobin, glucose and electrolyte concentrations are limited, with no obvious independent validation being available in the literature other than that provided by the manufacturers. If emergency clinical decisions are to be made on the basis of the haematological and biochemical information provided by these analysers, clinicians must be confident about the concordance of this information with venous analyses.

In order to evaluate the current situation, this prospective study aims to assess the accuracy of arterial blood gas analysers in determining haemoglobin, glucose, sodium and potassium concentrations, and compare results directly to simultaneous standard venous blood analysis in acutely unwell patients.

Correspondence to: Dr. Leonard M. Quinn
Directorate of Colorectal Surgery, Warrington and Halton Hospitals NHS Trust, Lovely Lane, Warrington WA5 1QG, UK
Email marc.quinn@doctors.org.uk

Materials and methods

One hundred acutely unwell adult (age >18) patients presenting to the emergency department undergoing simultaneous ABG (heparinised syringe), venous full blood count (EDTA syringe), venous plasma glucose (fluoride EDTA syringe) and venous serum urea and electrolyte

Table 1. Mean overall difference between arterial blood gas and venous analyser.

Parameter	Mean difference	Percentage difference	Range	*P* value (paired sign test)
Haemoglobin	0.91 g/dL	6.2	0–3 g/dL	<0.02*
Glucose	1.16 mmol/L	11.1	0–10.5 mmol/L	<0.012*
Sodium	1.9 mmol/L	1.4	0–4.3 mmol/L	<0.069
Potassium	0.33 mmol/L	8.8	0–1.57 mmol/L	<0.76

*statistically significant

(heparinised syringe) sampling were included in the study. Any patient with an intervention such as intravenous fluids or blood transfusion, or a significant time delay (exceeding 5 min) between sample collection, was excluded.

All ABG samples were analysed using the Bayer Health Systems machines, and all venous samples were analysed using Siemens Healthcare laboratory analysers. All machines were calibrated on a timely and regular basis to company specifications. Parameters recorded and analysed by both machines included haemoglobin, glucose, sodium and potassium concentrations. The results of these parameters were retrieved from the hospital information system (Sunquest ICE laboratory computer record), and ABG results for each parameter were compared directly with the venous analyser results.

Statistical analyses were undertaken using Statview statistical software. The primary outcome measured was the overall positive/negative difference between the two modalities for each of the parameters in all 100 patients. Statistical significance testing included use of the paired sign test. Those patient parameters underestimated and overestimated by the ABG analyser were then analysed in independent subgroups.

Results

The median age of the cohort was 67.1 years and there were equal numbers of men and women. The mean differences between the two modalities (ABG and venous) in assessing haemoglobin, glucose, sodium and potassium concentrations are summarised in Table 1.

Haemoglobin

A significant difference in the overall mean concentration of haemoglobin by 0.91g/dL was noted ($P<0.02$, paired sign test; range: 0–3 g/dL) with both over- and underestimation. Haemoglobin was underestimated in 36 patients (mean difference: 0.89 g/dL, $P<0.0001$, paired sign test) and overestimated in 64 patients (mean difference: 0.78 g/dL; $P<0.0001$, paired sign test).

Glucose

On comparing glucose concentrations, there was a significant mean difference of 1.16 mmol/L between the ABG analyser and the venous analyser (range: 0–10.5 mmol/L; $P<0.012$, paired sign test). Glucose levels were underestimated in 36 patients (mean difference: 1.54 mmol/L; $P<0.0001$, paired sign test). The ABG analyser overestimated glucose in 64 patients (mean difference: 0.91 mmol/L; $P<0.0001$, paired sign test).

Sodium

Overall mean difference in sodium concentrations between both the analysers was 1.9 mmol/L (range: 0–4.3 mmol/L), which approached statistical significance ($P<0.069$, paired sign test). Even at high sodium (>150 mmol/L) and low sodium (<130 mmol/L) levels, the ABG analyser reading was not significantly different from the venous analysed samples ($P<0.69$ for high levels, $P<0.2$ for low levels, paired sign test). Compared to the venous analyser, the ABG analyser underestimated sodium levels in 41 patients (mean difference: 2.03 mmol/L; $P<0.0001$, paired sign test) and overestimated sodium in 59 patients (mean difference: 0.06 mmol/L; $P<0.0001$, paired sign test).

Potassium

On comparing potassium concentrations between the two analysers, the overall mean difference was 0.33 mmol/L (range: 0–1.57mmol/L), which was not statistically significant ($P<0.76$, paired sign test). At high potassium values (>5 mmol/L), a significant difference of 0.44 mmol/L between analysers was observed ($P<0.0013$, paired sign test). This was not the case for potassium levels <3.5 mmol/L ($P<0.674$, paired sign test). When compared to the venous analyser, the ABG analyser underestimated potassium in 48 patients (mean difference: 0.42 mmol/L; $P<0.0001$, paired sign test) and overestimated potassium in 52 patients (mean difference: 0.28 mmol/L; $P<0.0001$, paired sign test).

Discussion

This study was undertaken to assess the concordance between arterial blood gas and standard venous laboratory analyser estimations of haemoglobin, glucose and electrolyte concentrations in critically ill patients presenting to the emergency department. As current literature comparing arterial and standard venous samples is limited, the aim was to clarify whether or not clinicians may be confident in the results of these two modalities being interchangeable in the diagnosis and management of these patients. The primary objective was to determine overall accuracy of the ABG analyser, rather than its ability to under- and overestimate these parameters. Although over- and underestimation differences have been described in the results section, its interpretation is of limited clinical significance and the authors use overall difference in the analysis process.

Provision of an early and accurate haemoglobin concentration is of paramount importance in the timely management of haemorrhaging patients, both to provide a baseline assessment of blood loss and for determination of

transfusion requirements. In the cohort studied here, a statistically significant overall mean difference between the ABG and venous haemoglobin concentrations was found, with the ABG analyser under- and overestimating venous values. There was no association between under- or overestimation and clinical condition.

A previous study by Ray *et al*. found ABG haemoglobin concentration had a weak correlation with venous haemoglobin concentration, and in the majority of cases was overestimated by the ABG analyser.[5] However, the major drawbacks of the study were an inability to apply these results directly to point-of-care analysers, and clarification about whether patients were actively bleeding or if they had received red cell transfusion. Sole reliance on ABG haemoglobin concentration may be misleading. In view of this, the authors would recommend that ABG haemoglobin concentrations be viewed with caution and decisions on transfusion should ideally be made based on standard venous results.

An accurate glucose value is crucial in the diagnosis of acute presentations such as impaired consciousness, particularly in the management of diabetic emergencies such as hypoglycaemia, and for the maintenance of strict glucose control in the critically ill. The present study found a mean difference between the two modalities to be statistically significant; however, its clinical significance is less. Nevertheless, the maximum difference was 10.5 mmol/L, which is of high clinical significance both in hypoglycaemic and hyperglycaemic states. Data from a Canadian study assessing arterial and capillary samples against venous samples found significantly better clinical agreement of venous samples with arterial blood gas samples compared to the capillary samples. However, considerable disparity between all three modalities led to frequent clinical disagreement.[6] Although a statistically significant difference has been determined between both analysers in the present study, the mean overall difference is small and of limited clinical significance. Again, it is recommended that venous plasma sampling confirmation be used as the gold standard for monitoring glucose levels.

Sodium and potassium abnormalities are common in the critically ill. Knowledge of the real-time electrolyte status is pivotal in deciding whether a biochemical derangement is a cause or complication. Regarding sodium, no statistically significant difference was found between the two analysers within or outside the physiological range. These findings are in keeping with previously published data from Turkey.[7] A similar study by Jain *et al*. reported a significant difference in sodium concentration between both analysers within the physiological range, which was not clinically significant as it fell within United States Clinical Laboratory Improvement Amendment (US CLIA) guidelines published in 2006. Outside the physiological sodium range they found the mean difference between both analysers to be unreliable.[8]

The US CLIA guidelines accept a difference of 4 mmol/L in sodium concentration and 0.5 mmol/L in potassium concentration from the gold standard calibration solutions.[9] Using the present results, it is possible to infer that sodium values reported by ABG analysers are sufficiently concordant with venous serum analysers for clinical decision-making in the acute scenario.

On assessment of potassium, the present study found no significant difference between both analysers, as was also demonstrated by Jain *et al*.[8] The accuracy of ABG potassium concentration compared to that obtained by venous analysers has also been studied in patients in cardiac arrest, and not found to be statistically different. However, this study deemed the limits of agreement to be too wide for safe reliance in clinical practice.[10] Furthermore, when the potassium value exceeded 5 mmol/L the ability of the ABG analyser to provide an accurate potassium value was compromised, leading to a significant difference between analysers. In view of this, the authors suggest that ABG potassium results may represent a fairly good reflection of the true result when within physiological limits but should be interpreted with extreme caution when the value exceeds 5 mmol/L, and ideally should be confirmed with standard venous serum laboratory analysers. Certainly, diagnosis of hyperkalaemia should not be made solely on the basis of an ABG analyser result.

There are a number of physiological reasons why the values of the parameters studied may differ between arterial and venous analysers. Arterial blood gas samples are obtained and stored in heparinised plasma, whereas venous samples in EDTA are used for the full blood count, fluoride EDTA for glucose, and serum for electrolytes. Each sample type is taken from separate sites within the circulation where physiological shifts are a constant occurrence. Therefore, such factors must be borne in mind in the interpretation of the results obtained by the two analyser types; however, accounting for such differences is beyond the scope of this study.

In terms of limitations, the study did not aim to assess whether or not the size of the difference had an effect on patient outcome. Thus, it is recommended that future studies take this into account. Furthermore, only one ABG machine and one standard venous analyser were used, and therefore future studies should assess the agreement between different machines and compare them individually to standard venous analysers.

In conclusion, when compared to standard laboratory venous analysers, there is a significant difference in estimations of haemoglobin, glucose and potassium concentration (>5 mmol/L) by arterial blood gas analysis. Therefore, these parameters should be viewed with caution in the management of the critically ill, and consequently it is recommended that they be confirmed by standard venous sample analysers. □

References

1 Myers GJ, Browne J. Point of care hematocrit and hemoglobin in cardiac surgery: a review. *Perfusion* 2007; **22** (3): 179–83.

2 Vos G, Engel M, Ramsay G, van Waardenburg D. Point of care blood analyzer during interhospital transport of critically ill children. *Eur J Emerg Med* 2006; **13** (5): 304–7.

3 Alexander PT. Timely information is key to critical care. *Health Manag Technol* 1999; **20** (11): 32.

4 Drenck N. Point of care testing in critical care medicine: the clinician's view. *Clin Chim Acta* 2001; **307** (1–2): 3–7.

5 Ray JG, Post JR, Hamielec C. Use of a rapid arterial blood gas analyzer to estimate blood hemoglobin concentration among critically ill adults. *Crit Care* 2002; **6** (1): 72–5.

6 Kanji S, Buffie J, Hutton B *et al*. Reliability of point-of-care testing for glucose measurement in critically ill adults. *Crit Care Med* 2005; **33** (12): 2778–85.
7 Budak YU, Huysal K, Polat M. Use of a blood gas analyzer and a laboratory autoanalyzer in routine practice to measure electrolytes in intensive care unit patients. *BMC Anesthesiol* 2012; **12**: 17.
8 Jain A, Subhan I, Joshi M. Comparison of the point-of-care blood gas analyzer versus the laboratory auto-analyzer for the measurement of electrolytes. *Int J Emerg Med* 2009; **2** (2): 117–20.
9 Centers for Medicare & Medicaid Services. Clinical Laboratory Improvement Amendments (CLIA). Baltimore: CMS, 2013 (www.cms.gov/Regulations-and-Guidance/Legislation/CLIA/index.html?redirect=/clia/).
10 Johnston HL, Murphy R. Agreement between an arterial blood gas analyser and a venous blood analyser in the measurement of potassium in patients in cardiac arrest. *Emerg Med J* 2005; **22** (4): 269–71.