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ORIGINAL RESEARCH

How closely do blood gas electrolytes and haemoglobin agree with serum values in adult emergency department patients: An observational study

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Abstract

Objective: The aims of this study were to establish the bias (mean difference) and 95% limits of agreement (LoA) between electrolyte values (sodium and potassium) and haemoglobin between whole blood analysed by the ED resuscitation room blood gas analyser and specimens analysed using standard techniques in the central hospital laboratory and to determine the proportion of analyses falling outside defined clinically acceptable LoA and pathology expert defined standards.

Methods: Prospective cohort study. Paired blood gas analyser and laboratory samples taken no more than 10 min apart were included. The primary outcome of interest was bias and 95% LoA by Bland–Altman analysis. Subgroup analyses for values outside the normal range were also conducted.

Results: Three hundred and fifty-two sample pairs were included in the analysis. For sodium concentration the bias was 0.6 mmol/L (95% LoA −3.3 to 4.6 mmol/L). For potassium concentration the bias was 0.21 mmol/L (95% LoA −0.36 to 0.79 mmol/L). For haemoglobin concentration the bias was −1.6 g/dL (95% LoA −10.2 to 6.9 g/dL). For sodium and haemoglobin concentrations, >95% of results fell within the defined clinically acceptable limits. For potassium concentration, >90% of results fell within the defined clinically acceptable limits. In general, serum sodium and potassium concentrations were slightly higher than blood gas levels and for haemoglobin serum levels were slightly lower.

Conclusion: Agreement between blood gas analysis and laboratory analysis for sodium, potassium and haemoglobin concentrations shows acceptable agreement for use in time critical clinical decision-making in ED.

Key words: *blood gas, electrolyte, emergency department, haemoglobin.*

Key findings

- Agreement between blood gas analysis and laboratory analysis for sodium, potassium and haemoglobin concentrations shows acceptable agreement for use in time critical clinical decision-making in ED.
- In general, serum sodium and potassium concentrations were slightly higher than blood gas levels and for haemoglobin serum levels were slightly lower.
- More than 90% of results fell within the defined clinically acceptable limits.

Introduction

In critically ill ED patients, rapid results for electrolytes and haemoglobin are often needed to inform urgent management decisions. This was highlighted in a recent case where serum sodium concentration on point of care (POC) blood gas analysis was 178 mmol/L and there was discussion among the resuscitation team about the accuracy of this result and its clinical implications. Other clinical scenarios where rapid results might influence management are unstable arrhythmias, seizures and acute blood loss.

There is often a more than 1 h delay to laboratory results for electrolytes and haemoglobin so for critically ill ED patients, POC blood gas analyses are often used to guide initial care. For this to be clinically justified, clinicians need to understand agreement (and non-agreement) between the POC and laboratory analysis methods.

There is little ED-specific evidence addressing this issue and current recommendations are conflicting. The aims of this study, conducted in an adult ED population, are to:

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1. Establish the bias and 95% limits of agreement between electrolyte values (sodium and potassium) and haemoglobin between whole blood analysed by the ED resuscitation room blood gas analyser and specimens analysed using standard techniques in the central hospital laboratory.
2. To determine what proportion of analyses for the parameters above using the blood gas analyser fall outside pre-defined clinically acceptable limits of agreement of sodium concentration ±5 mmol/L, potassium ±0.5 mmol/L and haemoglobin concentration ±10 g/dL and US Clinical Laboratory Improvement Amendment (USCLIA) standards.[1] USCLIA defines acceptable agreement for sodium concentration as ±4 mmol/L, potassium concentration as ±0.5 mmol/L and haemoglobin as ±7%.

Methods

This was an observational study undertaken at a metropolitan, university affiliated ED in Australia with an annual adult census of approximately 40 000. It included adult patients who underwent blood gas analysis and central laboratory analyses for electrolytes and haemoglobin concentrations. We excluded patients who had samples taken greater than 10 min apart, where drug or intravenous fluid administration had occurred between specimens or if they had previously been entered into the study.

Patients were identified by a prospectively collected list housed in a folder next to the ED resuscitation room blood gas analyser. Blood gas values were obtained by analysis of whole blood collected in a standard blood gas syringe using the resuscitation room blood gas analyser (Radiometer ABL 800 Flex, Copenhagen, Denmark). All staff using this machine were trained and accredited in its use and maintenance and quality assurance were provided by the hospital Pathology Department. For the central laboratory-analysed specimens, whole blood was placed in appropriate specimen collection tubes and analysed by medical scientists trained in the required techniques on hospital analysers (Siemens Advia 1800, Munich, Germany for serum electrolytes; Sysmex XE-2100 or Sysmex XT1800i haematology analysers, Kobe, Japan for haemoglobin). For electrolytes, analysis was on serum and for haemoglobin on whole blood.

Data was collected onto a piloted, project-specific data form and included patient demographics, ED diagnosis category, blood pressure, source of blood gas (i.e. arterial or venous) and analysis results.

Outcomes of interest were agreement between blood gas and central laboratory-analysed values for study parameters, agreement within pre-defined clinically relevant limits (sodium concentration ±5 mmol/L, potassium ±0.5 mmol/L and haemoglobin concentration ±10 g/dL) and agreement with USCLIA standards. Subgroup analysis was performed to investigate agreement by blood gas source and agreement in groups with high or low values outside the normal range.

Agreement was analysed by Bland–Altman agreement analysis with laboratory-analysed values being defined as the reference standard (Analyse-It™, Leeds, UK). The Bland–Altman method calculates the mean difference between two methods of measurement (the 'bias'), and 95% limits of agreement (1.96*standard deviation). It is expected that the 95% limits of agreement include 95% of differences between the two measurement methods. Agreement within pre-defined clinically acceptable limits and USCLIA standards was examined by descriptive statistics with 95% confidence intervals.

Calculation of sample size pre-hoc was challenging as previous papers did not report standard deviation of the difference between the measures. Post-hoc calculation using the standard deviations for the difference between measures found in our study and the method described by Altman[2] show that a sample size of 300 yields 95% confidence intervals around the limits of agreement of 0.4 mmol/L for sodium concentration, 0.06 mmol/L for potassium concentration and 0.9 for haemoglobin concentration. A recent similar study calculated similar sample size requirement.[3] To allow for missing data and exclusions we aimed for recruitment of a minimum of 400 sample pairs.

The project was approved as a quality assurance project by the Western Health Low Risk Ethics Panel. Patient consent for data collection was not required.

Results

Three hundred and fifty-two patients were included in the analysis. Sample

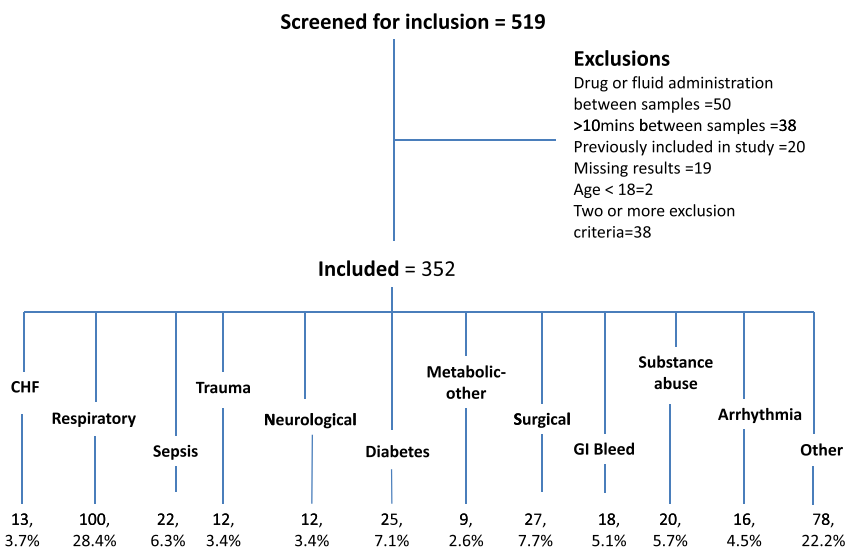

Figure 1. *Sample derivation.*

TABLE 1. *Results of agreement analysis*

Parameter	Group/subgroup	Number	Bias (average difference: serum – blood gas result)	95% limits of agreement
Sodium	Overall	346	0.6 mmol/L	–3.3 to 4.6 mmol/L
	Serum Na <130	23	0.8 mmol/L	–3.9 to 5.5 mmol/L
	Serum Na <120	4	0 mmol/L	–3.6 to 3.6 mmol/L
	Serum Na ≥145	21	0.5 mmol/L	–4.0 to 5.0 mmol/L
	Arterial blood gas specimens	55	1.4 mmol/L	–3.8 to 6.5 mmol/L
	Venous blood gas specimens	291	0.5 mmol/L	–3.1 to 4.1 mmol/L
Potassium	Overall	343	0.21 mmol/L	–0.36 to 0.79 mmol/L
	Serum K <3.5	20	0.13 mmol/L	–0.13 to 0.39 mmol/L
	Serum K >5	50	0.41 mmol/L	–0.21 to 1.03 mmol/L
	Serum K ≥6	13	0.41 mmol/L	–0.12 to 0.94 mmol/L
	Serum K <3 or >6	14	0.36 mmol/L	–0.12 to 0.84 mmol/L
	Arterial blood gas specimens	54	0.36 mmol/L	–0.29 to 1.00 mmol/L
	Venous blood gas specimens	289	0.19 mmol/L	–0.36 to 0.73 mmol/L
Haemoglobin	Overall	352	–1.6 g/dL	–10.2 to 6.9 g/dL
	Serum Hb <100	42	–1.4 g/dL	–12.9 to 10.1 g/dL
	Serum Hb ≤70	10	–1.9 g/dL	–11.8 to 8 g/dL
	Arterial blood gas specimens	55	0 g/dL	–7.6 to 7.5 g/dL
	Venous blood gas specimens	297	–1.9 g/dL	–10.5 to 6.7 g/dL

derivation is shown in Figure 1. Fifty-eight percent of patients were male with a median age of 70 years (interquartile range 57–81). Thirty-five (10%) had blood pressure ≤100 mmHg. Regarding type of blood gas, 297 were venous (84%, 95% CI 80–88%) and 55 were arterial samples (16%, 12–20%).

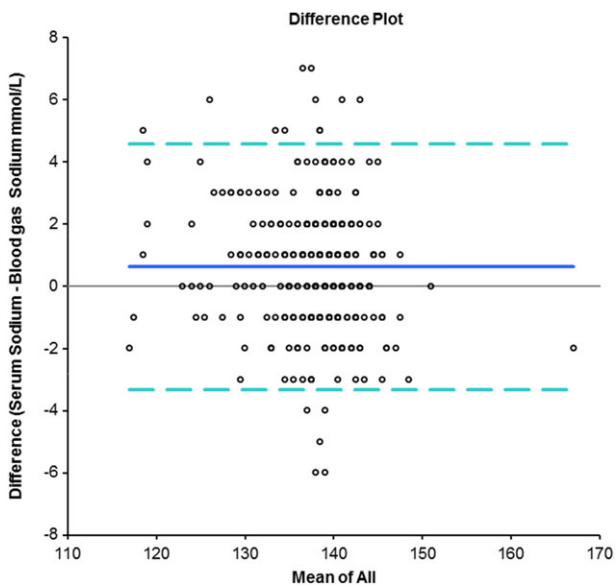

Figure 2. *Difference plot for sodium concentration. Bias (0.6); 95% limits of agreement (–3.3 to 4.6).*

Results of the agreement analysis are shown in Table 1 and Figures 2–4. Note that for potassium and sodium concentration the serum level was, in general, higher than the blood gas result. For haemoglobin the serum result was, in general, lower than the blood gas result.

The proportion of sample pairs with a difference of greater than the pre-defined clinically acceptable limits of agreement and USCLIA standards is shown in Table 2.

Discussion

It is well recognised in emergency medicine that for critically ill patients the delay to laboratory-analysed data for electrolytes and haemoglobin may be clinically relevant and potentially delay time critical treatment. POC blood gas analysers are available in the resuscitation area of most developed countries' ED and can provide

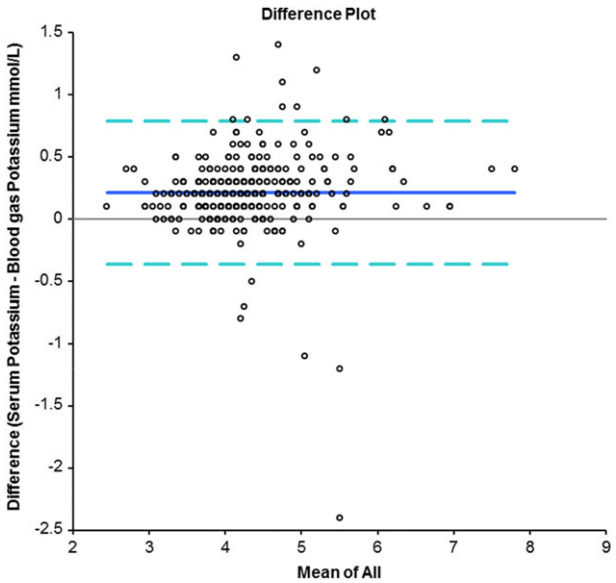

Figure 3. *Difference plot for potassium concentration. Bias (0.21); 95% limits of agreement (–0.36 to 0.79).*

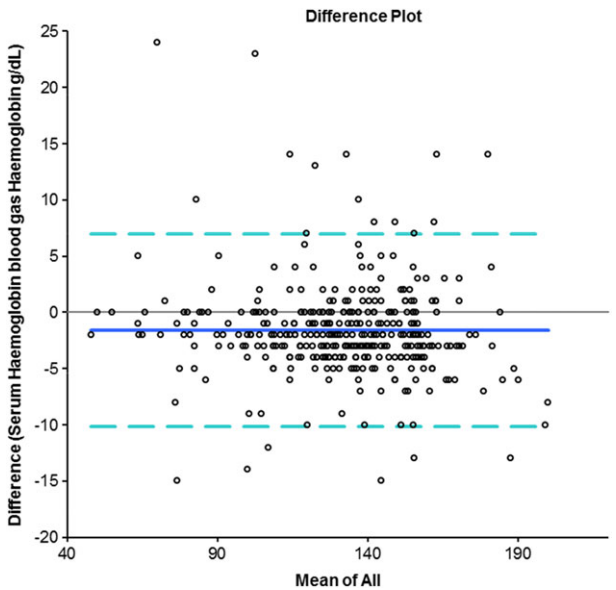

Figure 4. *Difference plot for haemoglobin concentration. Bias (–1.6); 95% limits of agreement (–10.2 to 6.9).*

fast data on these parameters. Previous research investigating the agreement of POC blood gas analysis results with laboratory-analysed results in critical care settings has been conflicting. Some authors have regarded agreement between these methods of analysis as unacceptable and recommended caution when interpreting POC blood gas analyser results.[4–6] Other research has suggested that agreement is acceptable for potassium concentration but not for sodium concentration.[7–9] Two previous studies, both from the ED setting with sample sizes of 200, have regarded agreement as clinically acceptable.[3,10] Our study, the largest ED-based study, agrees with these latter studies that, when taken in clinical context, agreement is close enough to guide time critical decision-making. Further, although subgroup sizes became small, the level of agreement seems to hold across the range of results and for both arterial and venous blood gas samples. Perhaps the only minor exception is potassium concentration above 5 mmol/L where the 95% limits of agreement go out of the order of 1 mmol/L. However, with the knowledge that serum levels are generally higher than blood gas levels, most experienced clinicians would regard the patient as hyperkalaemic and treat according to the clinical context.

With respect to haemoglobin concentration, initial concentration (blood gas or laboratory) is less important than clinical parameters such as pulse and blood pressure in dictating whether emergent transfusion is indicated. In the setting of acute blood loss, a dilutional fall in haemoglobin concentration is delayed. However, the initial haemoglobin value can inform treating clinicians about a patient's baseline haemoglobin (before the acute event), which may factor into transfusion decisions. A collation of the ED-based data for studies with sample sizes greater than 50 is shown in Table 3.

The reasons for the different recommendations about the clinical utility of POC blood gas electrolytes and haemoglobin are unclear. In some, if statistical difference was shown between the samples, they were regarded as not being clinically acceptable. However, statistical significance is not of clinical significance. A clinician interprets a result in a clinical context. Often the absolute value of a parameter is not as important as whether it is normal, high or low and the magnitude of the deviation from the normal range. Again the relative magnitude (a lot or a little) is often more important than the absolute number. Other studies have regarded that a proportion of sample-pair analyses are outside the USCLIA standards[1] as casting doubt on the POC blood gas analysis' utility. These standards principally relate to analytic performance and calibration verification. They were never intended to give an

TABLE 2. *Proportion agreement outside defined clinically acceptable limits of agreement and US CLIA standards*[1]

Parameter	*n*	Number outside defined clinically acceptable limits of agreement	Percent, 95% CI	Highest difference
Defined clinically acceptable limits of agreement				
Sodium concentration difference > ±5 mmol/L	346	8	2.3%, 1.1–4.7%	7 mmol/L
Potassium concentration difference > ±0.5 mmol/L	343	30	8.8%, 6.1–12.4%	2.4 mmol/L
Haemoglobin concentration difference > ±10 g/dL	352	13	3.7%, 2.1–6.4%	24 g/dL
USCLIA standards[1]				
Sodium concentration difference > ±4 mmol/L	346	14	4.1%, 2.3–6.9%	7 mmol/L
Potassium concentration difference > ±0.5 mmol/L	343	30	8.8%, 6.1–12.4%	2.4 mmol/L
Haemoglobin concentration difference > ±7%	352	28	8%, 5.4–11.4%	24 g/dL

TABLE 3. *Collation of ED-based evidence with sample >50 patients*

Parameter	Zhang[4] (*n* = 200)	Bloom[10] (*n* = 200)	This study (*n* = 352)
Sodium concentration (mmol/L, mean bias, 95% LoA)	3.04	3.36	0.6
	–1.24 to 7.31	0.18 to 6.54	–3.3 to 4.6
Potassium concentration (mmol/L, mean bias, 95% LoA)	0.43	0.46	0.21
	–0.29 to 1.16	–0.12 to 1.03	–0.36 to 0.79
Haemoglobin concentration (g/dL, mean bias, 95% LoA)	0.8	–2.9	–1.6
	–17.7 to 19.2	–17.1 to 11.2	–10.2 to 6.9

indication of acceptable clinical difference.

In our study we defined what we considered 'clinically acceptable agreement' based on experience and informal discussions with ED clinician peer groups over many years. We acknowledge that they represent one opinion and that clinicians may vary in their own definitions of clinically acceptable differences. Further, it is possible that what is considered a clinically acceptable difference may vary between clinical situations. This is an area worthy of further research.

Our results are also somewhat different from the published performance of the analyser.[11] It quotes bias of –0.3 mmol/L at potassium concentration of 3.4 and 0.23 mmol/L at a concentration of 6.3 mmol/L. For sodium concentration the quoted bias is 0.25–0.28 mmol/L across serum concentrations. For haemoglobin concentration this bias is 0.4 at haemoglobin concentration of 11 g/dL. The reasons for the larger biases in our study are unclear. Potential explanations include operator or sample preparation issues. These differences emphasise the importance of testing 'real world' agreement rather than relying on performance analysed in highly controlled non-clinical environments and reported by manufacturers.

This study has some limitations that should be considered when interpreting the results. While our aim was for a consecutive sample, the patient identification relied on nurses placing stickers in a book so it is likely that some cases were missed. In the study ED, blood gas analysis is generally used for patients with severe illness or in those with moderate–severe respiratory disease. This potentially adds bias, but in our opinion reflects real world practice in Australian EDs. The study was conducted at one hospital with a specified set of analytic machines. It may not be generalisable to other settings or analyser combinations.

Conclusion

Agreement between POC blood gas analysis and laboratory analysis for sodium, potassium and haemoglobin concentrations shows acceptable agreement for use in time critical clinical decision-making in ED.

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Competing interests

AMK is a member of the editorial board of *Emergency Medicine Australasia*.

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