ORIGINAL ARTICLE

Reliability of Arterial Blood Gas Analyzer for Electrolyte and Hemoglobin Measurement: A Method Comparison Study

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ABSTRACT

Background: Rapid assessment of electrolytes and hemoglobin is crucial in emergency and critical care. Arterial blood gas (ABG) analyzers are widely used as point-of-care devices. However, their agreement with central laboratory measurements remains uncertain because of methodological differences. This study aimed to evaluate the reliability of sodium, potassium, chloride, and hemoglobin values obtained from an ABG analyzer compared with those from a central laboratory autoanalyzer and to assess analytical acceptability using US Clinical Laboratory Improvement Amendments (CLIA) 2025 allowable error limits.

Materials and methods: In this prospective observational study, 200 paired arterial and venous samples from patients in the Emergency Department were analyzed. Arterial samples were processed on an ABG analyzer using direct ion-selective electrode (ISE) methodology, and venous serum electrolytes were measured on a central laboratory autoanalyzer using indirect ISE methodology. Hemoglobin was measured on a hematology analyzer. Paired comparisons were performed using the Wilcoxon signed-rank test, correlation was assessed with Spearman's coefficient, agreement was assessed with Bland–Altman analysis, and total error was compared with CLIA limits.

Results: ABG-derived sodium and potassium values were significantly lower than venous laboratory values, whereas chloride and hemoglobin values were significantly higher ($p < 0.001$). All analytes showed strong positive correlations. Bland–Altman analysis demonstrated acceptable agreement for sodium (bias, –2.8 mmol/L) and potassium (bias, –0.2 mmol/L), both within CLIA allowable limits. Chloride showed a total error of 6.43%, and hemoglobin showed a total error of 15.15%, indicating unacceptable analytical error.

Conclusion: ABG-derived sodium and potassium values demonstrated acceptable agreement with central laboratory measurements and can be used for rapid clinical decision-making in emergency settings. However, chloride and hemoglobin values should not be used interchangeably without institution-specific validation and correction equations.

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INTRODUCTION

Electrolytes play a vital role in maintaining cellular function and homeostasis in various tissues of the body. The major electrolytes include sodium (Na), potassium (K), and chloride (Cl). Almost all metabolic processes rely on or are regulated by electrolytes.[1] Disturbances in electrolyte homeostasis are commonly observed in various disorders, such as chronic renal failure, diabetes mellitus, sepsis, severe burns, trauma, and volume overload states such as cardiac failure. Electrolyte abnormalities are frequently associated with increased morbidity and mortality in critically ill patients. Therefore, timely identification and correction of electrolyte imbalance are essential.[2]

In clinical practice, electrolyte estimation is conventionally performed using serum obtained from venous blood analyzed by central laboratory autoanalyzers (AAs). Although these analyzers provide reliable and accurate results, the turnaround time (TAT), which may range from 20 to 30 minutes, including sample processing, can limit their usefulness in emergency situations. Point-of-care testing (POCT) devices, such as arterial blood gas (ABG) analyzers, allow rapid measurement of electrolytes from arterial whole blood within a few minutes, thereby facilitating prompt clinical decision-making in critically ill patients.

ABG analyzers are frequently used in emergency departments (EDs) and intensive care units (ICUs) to evaluate acid–base status and guide immediate clinical management. However, discrepancies between electrolyte and hemoglobin measurements obtained from ABG analyzers and central laboratory autoanalyzers have been reported in several studies.[3,4] These differences may arise because of methodological variations between the two systems. ABG analyzers employ direct ion-selective electrode (ISE) technology using heparinized whole blood, whereas central laboratory autoanalyzers typically use indirect ISE methods on diluted serum samples.[5] Such methodological differences can contribute to variations in the measured values.

Although POCT analyzers provide rapid results essential for timely clinical decision-making, their analytical accuracy may be limited by factors such as heparin interference, the effect of clotting, calibration stability, and differences in measurement methodology compared with central laboratory analyzers. ABG devices are primarily intended to analyze blood gas parameters such as pCO2, pO2, and pH to aid in the timely diagnosis of acid–base imbalance, which manifests with electrolyte disturbances. Consequently, clinicians may be hesitant to rely on ABG-derived electrolyte and hemoglobin values despite their rapid availability. Therefore, it is important for individual institutions to evaluate the degree of agreement between ABG analyzers and central laboratory autoanalyzers used in their clinical settings.[6,7] This evaluation will guide clinicians in the better management of critically ill patients.

The present study aimed to evaluate the reliability of electrolyte (Na, K, and Cl) and hemoglobin (Hb) measurements obtained using an ABG analyzer by comparing them with results from a central laboratory autoanalyzer in our tertiary care hospital. The primary objective was to assess the total error (TE) of ABG measurements in accordance with the US Clinical Laboratory Improvement Amendments (CLIA) 2025 guidelines,[8] using

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autoanalyzer results as the reference method to determine the reliability of ABG-derived measurements. The secondary objective was to derive an in-house regression equation to estimate venous electrolyte values from arterial measurements.

MATERIALS AND METHODS

This prospective observational study was approved by the Institutional Ethics Committee of Velammal Medical College Hospital and Research Institute, Madurai, on 26/02/2024 (IEC approval number: VMCIEC/036/2024). All procedures were conducted following the ethical standards of the institution and the Declaration of Helsinki. The study was conducted in the Department of Biochemistry from August 2023 to November 2023. A total of 200 samples collected from patients admitted to the Emergency Department (ED) were included. Both arterial and venous blood samples were collected from each patient at the time of admission before any medical intervention. Both analyzers underwent daily calibration and internal quality control (IQC) procedures before sample analysis to ensure analytical quality.

Arterial blood samples were collected by trained and skilled ED nurses who had received standardized training in the arterial puncture technique. Heparinized blood-gas syringes (commercially available plastic 2.0 mL disposable single-use syringes) were used for arterial blood sampling and were preflushed with 1 mL of heparin. Approximately 1.5 mL of arterial blood was collected and immediately analyzed using the ABL 800 Basic blood-gas analyzer, which employs direct ISE methodology.

For venous sampling, 2 mL of venous blood was collected in a red-top vacutainer containing a clot activator for electrolyte estimation, and 2 mL of whole blood was collected in an ethylenediaminetetraacetic acid (EDTA) vacutainer for hemoglobin estimation. Venous samples were transported to the central laboratory for analysis. Hemoglobin estimation was carried out using the Beckman Coulter DxH 600 Hematology Analyzer. After clotting, the samples were centrifuged at 3500 × g for 15 minutes, and the separated serum was used for analysis. Serum electrolytes (sodium, potassium, and chloride) were estimated using the Toshiba 120 FR autoanalyzer, which employs indirect ISE methodology.

Both arterial and venous blood samples were analyzed simultaneously, and the measured values were compared to determine the degree of agreement between the two methods. The acceptable limits of variation between the two methods were interpreted according to the United States Clinical Laboratory Improvement Amendments (US-CLIA) 2025 guidelines. Method comparison analysis was performed to assess the agreement between the ABG analyzer and the central laboratory autoanalyzer (AA).

The percentage total error (TE%) was calculated to evaluate analytical performance in accordance with Clinical and Laboratory Standards Institute (CLSI) and CLIA principles for method evaluation. The percentage total error (TE) was calculated using the following formula:[9]

$$\text{TE\%} = \frac{2 \times \text{SD of bias}}{\left[\dfrac{\text{Mean(method 1)} + \text{Mean(method 2)}}{2}\right]} \times 100$$

Where the standard deviation (SD) of bias represents the standard deviation of the differences between methods. Autoanalyzer measurements were considered the reference method for the estimation of total error and assessment of acceptability against CLIA-defined allowable error limits.

Statistical Analysis

Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) software (version 27.0). Continuous variables were tested for normality using the Shapiro–Wilk test. As the data were non-normally distributed, results were expressed as median (interquartile range). Paired comparisons between ABG analyzer and venous autoanalyzer measurements were performed using the Wilcoxon signed-rank test. Correlation between the two methods was assessed using Spearman's rank correlation coefficient, and linear regression analysis was used to derive predictive equations. Agreement between the two analytical methods was evaluated using Bland–Altman analysis, reporting the bias and 95% limits of agreement. $p < 0.05$ was considered statistically significant. Analytical acceptability was interpreted according to US-CLIA 2025 criteria, and Deming regression was applied where total error exceeded allowable limits.

RESULTS

A total of 200 paired arterial and venous samples were analyzed for electrolytes and hemoglobin using both the ABG analyzer in the Emergency Department and the central laboratory autoanalyzer. Of the study participants, 137 (68.5%) were male and 63 (31.5%) were female.

The sodium and potassium levels obtained using the ABG analyzer were significantly lower than those obtained using the autoanalyzer. In contrast, chloride and hemoglobin levels obtained using the ABG analyzer were significantly higher compared with the autoanalyzer results (Table 1).

Correlation analysis demonstrated a statistically significant positive correlation between arterial and venous measurements for sodium (Fig. 1A), potassium (Fig. 1B), chloride (Fig. 1C), and hemoglobin (Fig. 1D).

The regression equations obtained were as follows:

- Venous sodium = 0.8451 × ABG sodium + 18.089 (Fig. 1A)
- Venous potassium = 0.9419 × ABG potassium + 0.4113 (Fig. 1B)
- Venous chloride = 0.8735 × ABG chloride + 9.2823 (Fig. 1C)
- Venous hemoglobin = 0.8985 × ABG hemoglobin + 1.0772 (Fig. 1D)

These regression equations indicate a strong linear relationship between ABG and venous autoanalyzer measurements and may be used to estimate venous values from ABG measurements.

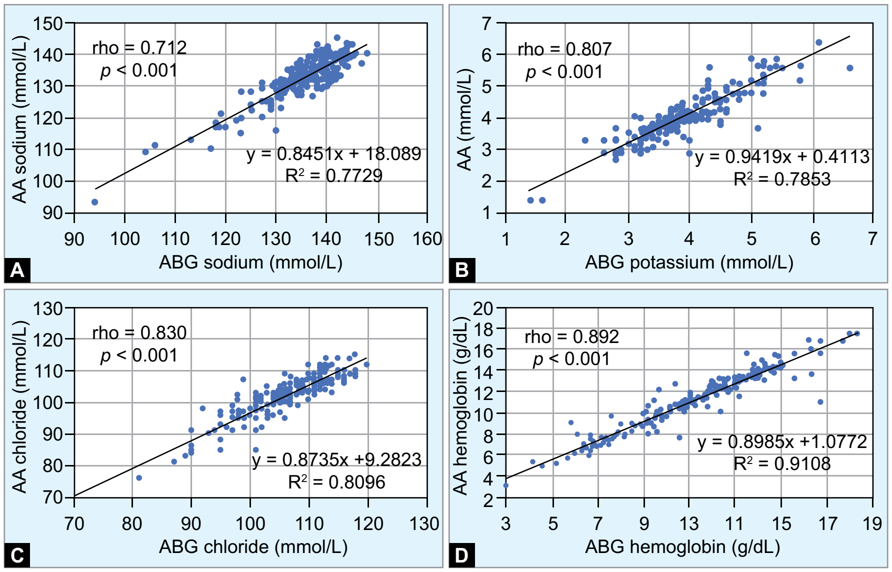
Agreement between the two methods, ABG analyzer and autoanalyzer, was assessed using Bland–Altman analysis, which evaluates the mean difference (bias) and the limits of agreement (LOA) (Table 2).

Sodium values measured by the ABG analyzer showed a negative bias of −2.8 mmol/L compared with autoanalyzer results (Fig. 2A). Potassium values showed a bias of −0.2 mmol/L for ABG measurements relative to the autoanalyzer (Fig. 2B). The bias of sodium and potassium was within the acceptable limits defined by the US-CLIA guidelines (Table 3).

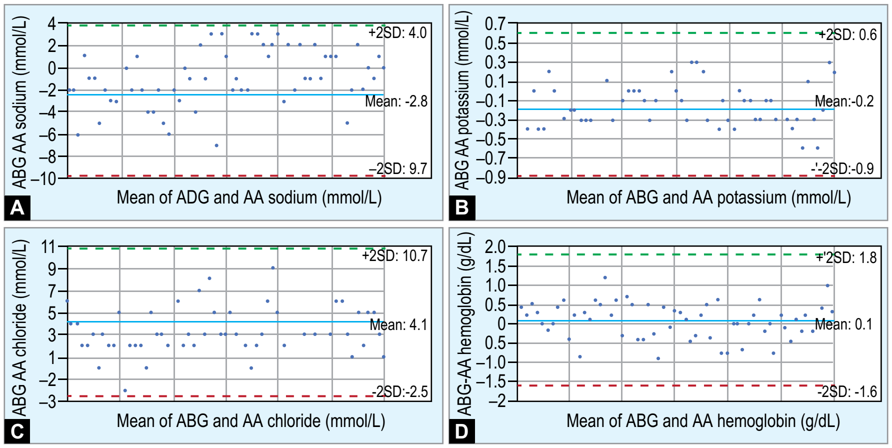
Table 1: Comparison of electrolyte and hemoglobin levels in arterial and venous blood

Study parameters	*Arterial blood (ABG analyzer)*	*Venous blood (Autoanalyzer)*	*p-value*
Sodium (mmol/L)	134 (130–137)	136 (132–139)	<0.001*
Potassium (mmol/L)	3.9 (3.5–4.3)	4.1 (3.7–4.7)	<0.001*
Chloride (mmol/L)	106 (102–111)	103 (99–106)	<0.001*
Hemoglobin (gm/dL)	11.5 (9.6–13.6)	11.4 (9.5–13.2)	<0.001*

Values were expressed as median (interquartile range); Comparison was performed using the Wilcoxon signed-rank test; A *p*-value < 0.05 was considered statistically significant



Figs 1A to D: Scatter diagram showing the correlation between ABG and autoanalyzer (AA) levels; Figure 1 demonstrates that venous autoanalyzer values can be derived from arterial ABG values using linear regression equations for each parameter



Figs 2A to D: Bland-Altman plots depicting the agreement between ABG and autoanalyzer (AA) levels

Table 2: Agreement between ABG and autoanalyzer measurements based on Bland–Altman analysis

Study parameters	*Mean difference*	*SD*	*95% upper limit*	*95% lower limit*
Sodium (mmol/L)	−2.8	3.5	9.7	−4.0
Potassium (mmol/L)	−0.2	0.4	0.9	−0.6
Chloride (mmol/L)	4.1	3.4	2.5	−10.7
Hemoglobin (gm/dL)	0.1	0.9	1.6	−1.8

For chloride (Fig. 2C), the ABG analyzer showed a positive bias of +4.1 mmol/L compared with the autoanalyzer. The total error percentage for chloride was 6.43%, exceeding the US-CLIA allowable total error of 5%, indicating that the difference between the two methods was not acceptable (Table 3).

Similarly, hemoglobin values measured by the ABG analyzer showed a bias of +0.1 g/dL (Fig. 2D). The total error calculated was 15.15%, which exceeded the US-CLIA allowable total error of 8%, indicating unacceptable agreement between the two methods (Table 3).

DISCUSSION

Table 3: Comparison of observed error with total allowable error (TEa)

Parameter	*TEa as per US CLIA 2025*	*Observed bias/ total error*
Sodium	±4 mmol/L	−2.8 mmol/L
Potassium	±0.3 mmol/L	−0.2 mmol/L
Chloride	±5%	6.43%
Hemoglobin	±8%	15.15%

For sodium and potassium, observed bias is expressed in mmol/L; For chloride and hemoglobin, total error is expressed as a percentage and compared with Clinical Laboratory Improvement Amendments (CLIA) allowable limits

The present study evaluated the reliability of ABG analyzer measurements for electrolytes (sodium, potassium, and chloride) and hemoglobin by comparing them with venous blood values obtained from a central laboratory autoanalyzer. ABG analyzers are widely used as point-of-care testing (POCT) instruments in emergency and critical care settings; therefore, establishing the degree of agreement between these two methods is essential for accurate and timely clinical decision-making. In this study, arterial sodium and potassium values showed strong correlation with venous measurements and were within acceptable limits defined by the US-CLIA guidelines, suggesting that they can be used reliably for rapid clinical decision-making. In contrast, chloride and hemoglobin demonstrated greater bias and total error exceeding allowable limits, indicating that these parameters may not be directly interchangeable between the two methods.

In our study, despite the strong correlations, statistically significant differences in mean values were observed between ABG and autoanalyzer measurements for all analytes. These differences could be attributed to variations in the sample type (whole blood/serum), measurement methodology (direct/indirect ISE), and calibration procedures. Arterial sodium and potassium values were lower than venous values. Lower arterial values could be explained by the dilutional effect of heparin, as arterial samples were collected in heparinized syringes.[10] Heparin, which is negatively charged, may interact with positively charged electrolytes, thereby reducing their measurable concentrations.[11] In addition, higher serum potassium levels than arterial potassium levels could be explained by the release of potassium by platelets during the clotting process.[1] Indirect ISE measurements can be affected by variations in plasma protein or lipid concentrations, which may affect sodium levels.[12] Although these variables were not assessed in this study, such matrix effects may contribute to the differences between ABG and laboratory measurements.

In the present study, all four analytes (sodium, potassium, chloride, and hemoglobin) demonstrated strong and statistically significant positive correlations between the ABG and autoanalyzer measurements. Similar findings have been reported in earlier studies, which described strong linear relationships between POCT and laboratory analyzers for major electrolytes.[2,3,13,14] These results indicate that ABG analyzers reliably reflect trends in electrolyte variations.

Because correlation does not imply agreement, Bland–Altman analysis was employed to assess the degree of agreement. Sodium and potassium exhibited minimal biases (–2.8 and –0.2 mmol/L, respectively), both of which remained within the total allowable error limits defined by the US-CLIA 2025 guidelines, indicating clinically acceptable agreement. These findings are consistent with observations from previous studies, which reported that ABG analyzers provide adequately reliable sodium and potassium measurements for urgent clinical use.[7]

In contrast, chloride and hemoglobin measurements showed biases exceeding the CLIA allowable limits. Chloride demonstrated a positive bias of 4.1 mmol/L, with a calculated total error of 6.43%, which exceeded the permissible 5%. Such discrepancies have been reported previously and are largely attributed to methodological differences between direct and indirect ISE measurements, as indirect ISE methods are susceptible to dilution and matrix effects.[2,5] Hemoglobin showed a bias of 0.1 g/dL, but its total error (15.15%) also exceeded the CLIA limit of 8%. ABG analyzers tend to measure slightly higher hemoglobin levels because they quantify hemoglobin in arterial blood, which has a higher oxygen saturation than venous blood analyzed in the central laboratory. Previous studies have similarly reported variability in hemoglobin measurements between ABG analyzers and laboratory systems because of differences in methodology, sample type, and calibration.[2,5]

The discrepancies observed between the two systems underscore the inherent methodological differences: ABG analyzers utilize direct ISE on undiluted whole blood, whereas laboratory autoanalyzers rely on indirect ISE on serum after dilution. The latter is influenced by serum proteins and lipids, potentially causing overestimation or underestimation, depending on the clinical conditions.[11] Furthermore, pH variations commonly seen in critically ill patients may influence electrolyte distribution, particularly potassium.[15]

To enhance clinical applicability, correction equations were derived using Deming regression to estimate venous laboratory values from the ABG results. These equations may be particularly valuable in emergency settings where immediate laboratory results are unavailable. Similar correction approaches have been recommended in previous method-comparison studies.[3,7]

Overall, while ABG analyzers provide reliable sodium and potassium values suitable for rapid decision-making, caution is warranted when interpreting chloride and hemoglobin measurements because the discrepancies exceed the acceptable analytical error limits.

These differences likely arise from analytical methodology, sample handling, and preanalytical factors such as heparin dilution. Similar discrepancies have been reported in previous studies, highlighting the importance of understanding local instrument performance characteristics when interpreting point-of-care results across diverse patient populations.

This study has certain limitations. First, extreme electrolyte values were not included; therefore, performance at very high or very low concentrations remains uncertain. Second, the correction equations derived in this study require prospective validation before routine clinical implementation. Finally, pediatric patients were excluded because a different ABG system is used in the pediatric intensive care unit (ICU), limiting generalizability to adult populations.

CONCLUSION

In our hospital, ABG-derived sodium and potassium measurements demonstrated acceptable agreement with central laboratory values and can be used reliably for rapid clinical decision-making. However, chloride and hemoglobin measurements exhibited unacceptable disagreement and should not be used interchangeably with laboratory values. For these analytes, the derived regression equations may help estimate venous results when urgent decisions are required. Because instruments and calibration practices differ across centers, each institution should perform its own method comparison study and, where needed, establish local correction factors to ensure safe clinical use of ABG-derived electrolyte and hemoglobin measurements.

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