



Original Contribution

Correlation between sodium, potassium, hemoglobin, hematocrit, and glucose values as measured by a laboratory autoanalyzer and a blood gas analyzer



İbrahim Altunok, Gökhan Aksel *, Serkan Emre Eroğlu

University of Health Sciences, Ümraniye Training and Research Hospital, Department of Emergency Medicine, Istanbul, Turkey

ARTICLE INFO

Article history:

Received 3 June 2018

Received in revised form 19 July 2018

Accepted 14 August 2018

Keywords:

Blood gas analysis

Clinical laboratory techniques

Reliability of results

Emergency department

ABSTRACT

Introduction: Blood gas analyzers can be alternatives to laboratory autoanalyzers for obtaining test results in just a few minutes. We aimed to find out whether the results from blood gas analyzers are reliable when compared to results of core laboratory autoanalyzers.

Materials and methods: This retrospective, single-centered study examined the electronic records of patients admitted to the emergency department of a tertiary care teaching hospital between May 2014 and December 2017. Excluded from the study were patients under 18 years old, those lacking data, those who had any treatment before the laboratory tests, those whose venous gas results were reported more than 30 minutes after the blood sample was taken and for whom any of the laboratory tests were performed at a different time, and recurrent laboratory results from a single patient.

Results: Laboratory results were analyzed from a total of 31,060 patients. The correlation coefficients for sodium, potassium, hemoglobin, hematocrit, and glucose levels measured by a blood gas analyzer and a laboratory autoanalyzer were 0.725, 0.593, 0.982, 0.958, and 0.984, respectively; however, there were no good, acceptable agreement limits for any of the parameters. In addition, these results did not change according to the different pH stages (acidosis, normal pH and alkalosis).

Conclusion: The two types of measurements showed a moderate correlation for sodium and potassium levels and a strong correlation for glucose, hemoglobin, and hematocrit levels, but none of the levels had acceptable agreement limits. Clinicians should be aware of the limitations of blood gas analyzer results.

© 2018 Elsevier Inc. All rights reserved.

1. Introduction

Routine laboratory measurements such as levels of glucose, hemoglobin, hematocrit, sodium, and potassium are essential parameters for deciding on the appropriate management of diseases in many patients, especially critically ill ones. A laboratory autoanalyzer (LAA) is the traditional and reliable instrument for measuring such values, but it is a time consuming method. Physicians need to make decisions much more quickly for patients in life-threatening situations than they do for stable patients. Moreover, in some clinical scenarios such as shock, time is of the essence, so it is necessary to treat the patient before finding out the exact underlying cause [1]. In such situations, a blood gases analyzer (BGA) is an alternative that can be used to obtain the test results in just a few minutes.

According to some authors, no test results have had more impact on patient care than BGA results [2]. However, there is only a small number of studies with limited numbers of patients evaluating the reliability of BGA results for sodium, potassium, hemoglobin, hematocrit, and glucose values. The literature on the reliability of BGA is controversial. There are studies reporting either strong correlations or significant differences between BGA and LAA results [3–5]. We believe that there is need for further studies comparing these methods in greater numbers of patients.

In this study, we aimed to find out whether BGA results for sodium, potassium, hemoglobin, hematocrit, and glucose in venous blood are reliable by examining data from 31,060 patients. To do so, we compared the of BGA results with LAA results. To our knowledge, no other study has investigated this topic with a sample size similar to ours.

2. Materials and methods

This study was performed, following ethical committee approval, by retrospectively examining the electronic records of patients admitted to the emergency department (ED) of a tertiary care teaching hospital

* Corresponding author at: Armağanevler Mahallesi, Sirt sokak, Atapol Rezidans, A5 Blok, No: 32, Ümraniye, Istanbul, Turkey.

E-mail address: aksel@gokhanaksel.com (G. Aksel).

between May 2014 and December 2017. The annual mean patient admission to the ED where the study was performed is approximately 600,000 patients; of these, approximately 27.5% are children and 72.5% are adults.

2.1. Patient inclusion and exclusion criteria

We screened the data of all the adult patients who were admitted to the ED during the study period using the hospital's electronic patient record management system. Patients who had results for initial biochemistry, hemogram, and venous blood gases (VBGs) taken at the same time and with the same protocol number for all three tests were included the study. Patients under 18 years old, lacking one or more VBG or LAA parameters, showing hemolysis in laboratory tests, or having had any treatment before the laboratory tests were excluded from the study. Patients whose VBG results were reported more than 30 minutes after their blood sample was taken and for whom any of the three laboratory tests were taken at different times or with a different test protocol number were excluded, as were recurrent laboratory results from a single patient.

2.2. Laboratory protocols and analyses

Heparinized syringes (PICO50 Arterial Blood Sampler – Radiometer Medical ApS, Brønshøj, Denmark) were used to obtain venous blood samples at bedside in the ED, and the samples were analyzed by a BGA (Radiometer ABL 700 Blood Gas Analyzer, Radiometer Medical ApS, Brønshøj, Denmark) located in the ED and calibrated six times a day. Venous blood samples for whole blood count were analyzed with a hematology analyzer (Abbott Cell-Dyn 3700 Hematology Analyzer, IL, USA). Finally, biochemistry analyses were performed by LAA with an indirect ion-selective electrode (ISE) diluted method (ARCHITECT ci4100 Clinical Chemistry Analyzer, IL, USA, using a 2P32 ICT sample diluent kit). The hematology and biochemistry analyzers are both located in the core laboratory of the hospital, and the samples were transferred to the laboratory by a pneumatic system within half an hour of collection.

During the study period, the biochemistry and hematology analyzers were calibrated at 24-hour intervals according to the manufacturers' instructions. Two types of controls (normal and abnormal) were to be run every 8 h and following calibration. The imprecision of the ICT assays for the serum samples was $\leq 1.5\%$ for sodium and $\leq 2.7\%$ for potassium.

2.3. Data collection

The age and sex of the patients and the glucose, hemoglobin, hematocrit, sodium, and potassium values measured by either BGA or LAA were recorded from the hospital electronic patient record management system. To investigate whether these values were affected by different pH stages, the patients were classified into an acidosis group (pH < 7.35), a normal pH group (pH between 7.35 and 7.45), and an alkalosis group (pH > 7.45). Also, the patients' ICD-10 codes were recorded, and their diseases were classified as respiratory, circulatory, digestive, nervous system, endocrine, muscle/bone, genitourinary, or other problems, muscle/bone trauma, or intoxication.

2.4. Statistical analysis

SPSS v25.0 for Mac OS X was used to analyze the data (Chicago, IL, USA). The normality of the data distribution was determined by the Kolmogorov–Smirnov test. Normally distributed data were expressed as the mean and standard deviation, while the rest were expressed as the median and percentage. Pearson correlation coefficients were calculated for each parameter; a value >0.8 was considered to be a strong correlation. A Bland–Altman test with 95% confidence interval (CI) limits of agreement was used to assess the agreement between

LAA and BGA results. The laboratory results of BGA for each parameter were classified as normal test results (the ones in normal range) and abnormal test results (the ones out of normal range). The sensitivity and specificity of BGA in predicting abnormal laboratory results were determined, and positive and negative likelihood values, positive and negative likelihood ratios and accuracy of the test were calculated to determine the test characteristics. The central lab results (hemogram and biochemistry) were accepted as “Gold Standard” for comparison.

3. Results

The electronic records of a total of 59,221 patients were screened retrospectively. After excluding recurrent laboratory results for individual patients at the same presentation ($n = 3229$), records lacking one or more types of laboratory data, having erroneous/suspicious results, or showing hemolysis ($n = 23,392$), and those with a BGA processing time over 30 min ($n = 1540$), a final total of 31,060 patients were included in the study. Table 1 shows the demographic and clinical characteristics of the patients.

The correlation coefficients for sodium, potassium, hemoglobin, hematocrit, and glucose levels measured by BGA and core LAA were 0.725, 0.593, 0.982, 0.958, and 0.984, respectively. There was a strong correlation for hemoglobin, hematocrit, and glucose and a moderate correlation for sodium and potassium (Table 2).

When a Bland–Altman analysis was performed to assess the agreement between results of BGA and LAA, the mean differences found were 1.93 ± 4.2 mmol/L for sodium, 0.35 ± 0.8 mmol/L for potassium, 0.68 ± 0.8 g/dL for hemoglobin, $2.80 \pm 2.5\%$ for hematocrit, and 4.98 ± 24.4 mg/dL for glucose. Although the agreement for potassium, hemoglobin, and hematocrit was slightly better than for the others, there was poor agreement for all of the parameters (Fig. 1).

When the patients were grouped according to pH stage, there were 5723 patients (18.4%) in the acidosis group, 17,311 patients (55.7%) in the normal pH group, and 8026 patients (25.8%) in the alkalosis group. The Bland–Altman analyses were performed for each pH stage, and similar to the results of the analysis in which all the samples were included, there was again poor agreement for all of the parameters. Also, the agreement for sodium, potassium, hemoglobin, and hematocrit in the acidosis group was poorer than the agreement for the same parameters in other pH groups, while the agreement was again poor but similar between the normal pH and alkalosis groups (Table 2).

The highest sensitivity of blood gas analyzer detecting abnormal test results was in glucose with a sensitivity of 98.1%, while

The highest sensitivity of BGA for detecting abnormal test results was 98.1% for glucose levels, while the lowest sensitivity was 51.4% for potassium levels. The performance results of BGA were detailed in Table 3.

Table 1
Demographic and clinical characteristics of the patients.

Sex (n/%)	Male	15,430 (50.3)
	Female	15,630 (49.7)
Age (mean \pm SD)		56.95 \pm 10.8
Disease (n/%)	Respiratory problems	6973 (22.5)
	Circulatory problems	4473 (14.4)
	Digestive problems	4119 (13.3)
	Nervous system problems	3663 (11.8)
	Intoxication	2345 (7.5)
	Endocrine disorders	2245 (7.2)
	Muscle/bone problems and trauma	1195 (3.8)
	Psychiatric problems	1028 (3.3)
	Genitourinary problems	905 (2.9)
	Other problems	4114 (13.2)
	Total	31,060 (100)

SD = Standard deviation.

Table 2

Means and mean differences of sodium, potassium, hemoglobin, hemotocrit and glucose levels in venous blood gases and routine laboratory results in each pH stages.

pH stage		Venous blood gases results Mean \pm SD	Routine laboratory results Mean \pm SD	Mean difference Mean \pm SD ^a	Agreement limits with 95% ^a	Pearson correlation coefficients
Acidosis group <i>n</i> = 5723 (18.4%)	Na (mmol/L)	137.5 \pm 7.4	138.5 \pm 5.3	0.97 \pm 5.7	−10.2 to 12.1	0.643
	K (mmol/L)	4.6 \pm 1.8	4.8 \pm 0.9	0.22 \pm 1.6	−2.9 to 3.4	0.412
	Hb (g/dL)	13.0 \pm 2.8	12.3 \pm 2.4	0.68 \pm 0.8	−0.9 to 2.3	0.962
	Htc (%)	39.9 \pm 8.3	37.4 \pm 7.1	2.48 \pm 2.7	−2.8 to 7.8	0.949
	Glu (mg/dL)	187.5 \pm 116.6	184.9 \pm 132.9	2.57 \pm 32.4	−60.9 to 66	0.975
Normal pH group <i>n</i> = 17,311 (55.7%)	Na (mmol/L)	136.2 \pm 5.4	138.1 \pm 4.3	1.89 \pm 3.8	−5.6 to 9.3	0.715
	K (mmol/L)	4.1 \pm 0.6	4.49 \pm 0.5	0.38 \pm 0.4	−0.4 to 1.2	0.760
	Hb (g/dL)	13.3 \pm 2.4	12.616 \pm 2.1	0.7 \pm 0.7	−0.7 to 2.1	0.983
	Htc (%)	40.9 \pm 7.3	38.0 \pm 6.1	2.92 \pm 2.4	−1.8 to 7.6	0.959
	Glu (mg/dL)	164.4 \pm 102.4	159.9 \pm 115.6	4.56 \pm 23.8	−42.1 to 51.2	0.951
Alkalosis group <i>n</i> = 8026 (25.8%)	Na (mmol/L)	134.8 \pm 6.3	137.5 \pm 5.5	2.70 \pm 3.7	−4.6 to 10	0.808
	K (mmol/L)	3.9 \pm 0.6	4.30 \pm 0.6	0.4 \pm 0.4	−0.4 to 1.2	0.816
	Hb(g/dL)	13.0 \pm 2.5	12.4 \pm 2.2	−0.63 \pm 0.8	−1.9 to 0.9	0.949
	Htc (%)	39.9 \pm 7.5	37.2 \pm 6.3	2.77 \pm 2.6	−2.3 to 7.9	0.962
	Glu (mg/dL)	155.2 \pm 81	147.6 \pm 90.4	2.57 \pm 32.4	−60.9 to 66.1	0.985
All patients <i>n</i> = 31,060 (total)	Na (mmol/L)	136.1 \pm 6.1	137.5 \pm 5.5	1.93 \pm 4.2	−6.4 to 10.2	0.725
	K (mmol/L)	4.2 \pm 1.0	4.30 \pm 0.6	0.35 \pm 0.8	−1.2 to 1.9	0.593
	Hb (g/dL)	13.2 \pm 2.5	12.4 \pm 2.2	0.68 \pm 0.8	−0.8 to 2.2	0.982
	Htc (%)	40.5 \pm 7.6	37.2 \pm 6.3	2.80 \pm 2.5	−2.2 to 7.8	0.958
	Glu (mg/dL)	166.3 \pm 100.8	147.6 \pm 90.4	4.98 \pm 24.4	−42.8 to 52.8	0.984

^a The results were obtained with the Bland-Altman analyses, SD: Standard Deviation, Hb = Hemoglobin, Htc: Hematocrit, Glu: Glucose.

4. Discussion

Laboratory results such as sodium, potassium, hemoglobin, hematocrit, and glucose levels give valuable information to physicians about the condition of patients and are essential for correct diagnoses. Physicians need such laboratory results more immediately for critically ill patients so that therapeutic interventions can be started without delay.

Both hyperkalemia and hypokalemia are associated with poor clinical outcomes such as hospitalization, cardiovascular disease, or death [6,7]. Hyperkalemia, in particular, can induce or worsen cardiac arrhythmias, and it is associated with significantly increased mortality [8–11]. As severe hyperkalemia is regarded as a clinical emergency, immediate medical interventions are needed [12]. Likewise, sodium disorders are associated with an increased risk of morbidity and mortality [13]. Glucose disorders, especially hypoglycemia, are also associated with significant morbidity (physical as well as psychological), reductions in quality of life, and risk of death [14–16].

It is well known that hemorrhage is one of the most common causes of death in severely injured trauma patients. It is also the most common potentially preventable cause of early death from trauma when early treatment have been initiated and essential blood products have been delivered rapidly [17–21]. Patients with class III or IV hemorrhagic shock especially require rapid blood transfusions to prevent serious damage [22]. Vital signs are the primary indicators for the classification of the shock level and the initiation of early blood product replacement treatment in hemorrhagic shock patients, while hemoglobin and hematocrit levels are essential for determining the maintenance treatment strategy and the prognosis of the patient.

Point-of-care tests (POCTs) provide immediate information to physicians about patients' conditions, making it possible to reduce patients' morbidity and mortality [23]. BGA, which gives results for sodium, potassium, hemoglobin, hematocrit, and glucose in just minutes, is accepted as a POCT for critically ill patients by some authors but not by others because of concerns about its reliability. It is necessary to validate the reliability of BGA with further studies with larger sample sizes in order to clarify the controversial results reported in previous studies.

A study by Jain et al. [4] analyzed 200 paired samples and found no significant difference between the potassium values measured by BGA and LAA, while there was a significant difference between the sodium values. In another study [3] with more paired sample analyses

(*n* = 1094 patients), in contrast to our results, although the correlation for chloride was moderate and the others were high, it was reported that all the parameters (sodium, potassium, hemoglobin, hematocrit, glucose, and chloride) measured by BGA were reliable.

Forty arterial blood gas samples were analyzed with two BGAs and a core LAA in a study conducted by Uyanik et al. [5]. Their results revealed that sodium, chloride, calcium, and glucose showed poor correlation, while the variability of potassium between the BGA and LAA was negligible. They concluded that BGAs and LAAs demonstrate variable performance, and not all the tests met the minimum performance goals; thus. The authors warned clinicians about the limitations of the assays.

Leina et al. [24] found that potassium, sodium, calcium, and lactate levels (*n* = 30 paired samples) measured with BGA and LAA had good correlations with good agreements, and they concluded that these methods can be used in different clinical settings for critical care management. On the other hand, they found that the variability of sodium, hemoglobin, and hematocrit levels measured by BGA was significant and suggested confirming the results for these variables with the LAA results.

Gavala et al. [23] found that BGA results were significantly lower than LAA values, with almost 30% of all the examined parameters beyond the United States Clinical Laboratory Improvement Amendment accepted biases. The authors concluded that BGA significantly underestimated the values of sodium, potassium, hemoglobin, and hematocrit compared to LAA so that values are not interchangeable between the two methods.

A study conducted by Solak [25] had one of the largest sample size compared to other studies (*n* = 2557 patients' laboratory results) but included only the sodium levels measured by BGA and LAA. The author classified blood pairs as hyponatremia, eunatremia, and hypernatremia according to the LAA results. The study results showed significant differences between the BGA and LAA results in all the sodium groups.

In the largest study previously published about this topic (*n* = 11,000 paired samples, analyzed retrospectively), Mirzazadeh et al. [26] found good agreements between the BGA and LAA results for sodium, potassium and calcium and concluded that BGA can be accepted as a POCT for critically ill patients.

Our study results showed that the BGA and LAA results for hemoglobin, hematocrit, and glucose levels were strongly correlated, but the

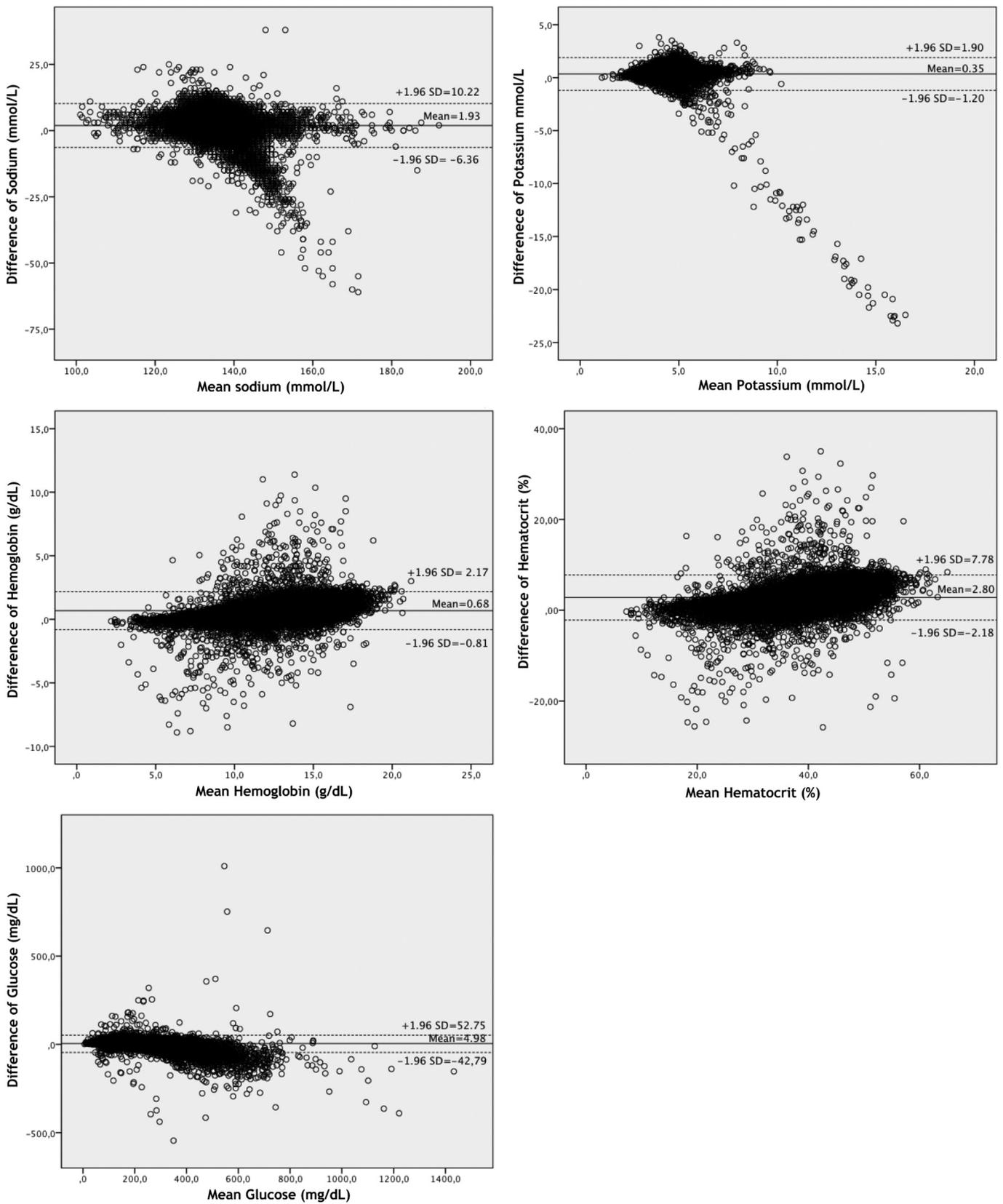


Fig. 1. Means and mean differences of sodium, potassium, hemoglobin, hematocrit, and glucose levels in venous blood gases and routine laboratory results according to Bland-Altman analyses.

results for sodium and potassium were only moderately correlated. We also found that the correlations of all the parameters were poorer in the acidosis group, especially for the potassium levels.

According to the Bland-Altman analyses, there was no good agreement in measurements by BGA and LAA for sodium, potassium, hemoglobin, hematocrit, or glucose. We also found that, while the

Table 3
Test performance of blood gas analyzer.

	Sodium	Potassium	Glucose	Hemoglobin	Hematocrit
Sensitivity	85.6% (84.8–86.4%)	51.4% (50.1–52.7%)	98.1% (97.9–98.3%)	82.9% (81.8–83.9%)	72.2% (71.4–73%)
Specificity	64.1% (63.5–64.7%)	88.9% (88.6–89.3%)	61.1% (60.2–62.1%)	88.8% (88.4–89.2%)	75.1% (74.4–75.7%)
PPV	24.6% (43.3–44.3%)	49.7% (1–3%)	83.4% (83.1–83.7%)	60.3% (59.4–61.2%)	66.7% (66.1–67.3%)
NPV	93.2% (92.8–93.5%)	89.6% (89.3–89.8%)	94.2% (93.6–94.7%)	96.2% (96–96.4%)	79.7% (79.2–80.1%)
PLR	2.4 (2.3–2.4)	4.7 (4.5–4.9)	2.5 (2.5–2.6)	7.4 (7.1–7.7)	2.9 (2.8–3)
NLR	0.2 (0.2–0.2)	0.6 (0.5–0.6)	0.03 (0.03–0.03)	0.2 (0.2–0.2)	0.4 (0.4–0.4)
Accuracy	69.4% (69.9–69.9%)	82.4% (81.9–82.8%)	66.55% (66–67.1%)	87.8% (87.4–88.2%)	73.9% (73.4–74.4%)

PPV: Positive predictive value, NPV: Negative predictive value, PLR: Positive likelihood ratio, NLR: Negative likelihood ratio.
Test performance metrics were all given with 95% confidence intervals.

agreement was poorer in the acidosis group, the agreements for all the parameters in any pH stage—acidosis, normal pH, or alkalosis—were also poor.

The performance results of BGA were highly variable for each parameter. The sensitivity of the test predicting the abnormal glucose and sodium levels was high (98.1% and 85.6%, respectively) but the specificity of the test for same parameters was limited with 61.1% and 64.1%. Sensitivity of the BGA was lower in potassium, hemoglobin and hematocrit, while specificity for potassium levels was relatively high with 88.9%. According to the test performance metrics, we believe that BGA may be considered as a screening test for detecting abnormal glucose levels. Because of low sensitivity levels, it doesn't seem a good screening test for other parameters, especially for the potassium levels.

In conclusion, none of the results measured by BGA has acceptable agreement, although there were strong correlations for hemoglobin, hematocrit, and glucose. It may be questionable whether potassium has an acceptable agreement (−1.2 to 1.9), but we believe that this range is wide enough for a physician's misdiagnosis. It is also remarkable that this range widened (−2.9 to 3.4) when acidosis was present.

Although some authors have suggested that BGA can be used for first-line assessments of critical patients, our study results did not support this suggestion [3]. Based on the results of the present study, we believe that there can be significant differences between BGA and LAA results for sodium, potassium, hemoglobin, hematocrit, and glucose levels. We suggest using LAA to confirm abnormal laboratory results measured by BGA, especially when the results are irrelevant to the clinical symptoms and findings of the patient. In the scenario in which the manifestation of the patient and the results measured by BGA are compatible, it would be sensible to initiate treatment according to the BGA results until they are unconfirmed by LAA results. Finally, we believe that BGA has poor reliability for use as a POCT. As the sample sizes of previously published studies were too limited compared with the numbers in our study, we believe that the present study adds valuable information to our knowledge of the reliability of BGA.

5. Limitations

The limitations of our study were its being single-centered and examining the data of the patients retrospectively.

6. Conclusion

The results of the present study revealed that there were moderate correlations for sodium and potassium and strong correlations for glucose, hemoglobin, and hematocrit levels measured by BGA and LAA; however, there were no acceptable agreement limits for any of the parameters. Clinicians should be aware of the limitations of BGA results

in case they need to use them for first-line assessments of critically ill patients.

References

- Rahim-Taleghani S, Fatemi A, Alavi Moghaddam M, Shojaee M, Abushouk AI, Forouzanfar MM, et al. Correlation of central venous pressure with venous blood gas analysis parameters, 20, a diagnostic study. *Turk J Emerg Med* 2016 Nov;17(1):7–11 (eCollection 2017 Mar). <https://doi.org/10.1016/j.tjem.2016.09.006>.
- Clinical and Laboratory Standards Institute. Blood gas and pH analysis and related measurements; approved guideline. CLSI Document C46-A2. 2nd ed. Pennsylvania, USA: Clinical and Laboratory Standards Institute Wayne; 2009.
- Uysal E, Acar YA, Kutur A, Cevik E, Salman N, Tezel O. How reliable are electrolyte and metabolite results measured by a blood gas analyzer in the ED? *Am J Emerg Med* 2016 Mar;34(3):419–24. <https://doi.org/10.1016/j.ajem.2015.11.025> [Epub 2015 Nov 26].
- 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.
- Uyanik M, Sertoglu E, Kayadibi H, Tapan S, Serdar MA, Bilgi C, et al. Comparison of blood gas, electrolyte and metabolite results measured with two different blood gas analyzers and a core laboratory analyzer. *Scand J Clin Lab Invest* 2015;75:97–105.
- Gilligan S, Raphael KL. Hyperkalemia and hypokalemia in CKD: prevalence, risk factors, and clinical outcomes. *Adv Chronic Kidney Dis* 2017 Sep;24(5):315–8. <https://doi.org/10.1053/j.ackd.2017.06.004>.
- Hayes John, Kalantar-Zadeh Kamyar, Jun L Lu, Turban Sharon, Anderson John E, Kovesdy Csaba P. Association of hypo- and hyperkalemia with disease progression and mortality in males with chronic kidney disease: the role of race. *Nephron Clin Pract* Mar 2012;120(1):c8–c16. <https://doi.org/10.1159/000329511> [Published online 2011 Dec].
- Lowrie EG, Lew NL. Death risk in hemodialysis patients: the predictive value of commonly measured variables and an evaluation of death rate differences between facilities. *Am J Kidney Dis* 1990;15:458–82.
- Iseki K, Uehara H, Nishime K, Tokuyama K, Yoshihara K, Kinjo K, et al. Impact of the initial levels of laboratory variables on survival in chronic dialysis patients. *Am J Kidney Dis* 1996;28:541–8.
- Hayes J, Kalantar-Zadeh K, Lu JL, Turban S, Anderson JE, Kovesdy CP. Association of hypo- and hyperkalemia with disease progression and mortality in males with chronic kidney disease: the role of race. *Nephron Clin Pract* 2012;120:c8–16.
- Kovesdy CP, Regidor DL, Mehrotra R, Jing J, McAllister CJ, Greenland S, et al. Serum and dialysate potassium concentrations and survival in hemodialysis patients. *Clin J Am Soc Nephrol* 2007;2:999–1007.
- Kovesdy CP. Updates in hyperkalemia: outcomes and therapeutic strategies. *Rev Endocr Metab Disord* 2017;18(1):41–7. <https://doi.org/10.1007/s11154-016-9384-x>.
- Braun MM, Barstow CH, Pyzocha NJ. Diagnosis and management of sodium disorders: hyponatremia and hypernatremia. *Am Fam Physician* 2015 Mar 1;91(5):299–307.
- Amiel SA, Dixon T, Mann R, Jameson K. Hypoglycaemia in type 2 diabetes. *Diabet Med* 2008;25(3):245–54.
- Clarke W, Jones T, Rewers A, Dunger D, Klingensmith GJ. Assessment and management of hypoglycemia in children and adolescents with diabetes. *Pediatr Diabetes* 2009;10(Suppl. 12):134–45.
- Cryer PE, Davis SN, Shamooh H. Hypoglycemia in diabetes. *Diabetes Care* 2003;26(6):1902–12.
- Acosta JA, Yang JC, Winchell RJ, Simons RK, Fortlage DA, Hollingsworth-Fridlund P, et al. Lethal injuries and time to death in a level I trauma center. *J Am Coll Surg* 1998;186(2):528–33.

- [18] Baker CC, Oppenheimer L, Stephens B, Lewis FR, Trunkey DD. Epidemiology of trauma deaths. *Am J Surg* 1980;140(3):144–50.
- [19] Kauvar DS, Lefering R, Wade CE. Impact of hemorrhage on trauma outcome: an overview of epidemiology, clinical presentations, and therapeutic considerations. *J Trauma* 2006;60:S3–11.
- [20] Tien HC, Spencer F, Tremblay LN, Rizoli SB, Brennehan FD. Preventable deaths from hemorrhage at a level I Canadian trauma center. *J Trauma* 2007;62:142–6.
- [21] Nunez TC, Dutton WD, May AK, Holcomb JB, Young PP, Cotton BA. Emergency department blood transfusion predicts early massive transfusion and early blood component requirement. *Transfusion* 2010 Sep;50(9):1914–20. <https://doi.org/10.1111/j.1537-2995.2010.02682.x>.
- [22] Choi SB, Park JS, Chung JW, Kim SW, Kim DW. Prediction of ATLS hypovolemic shock class in rats using the perfusion index and lactate concentration. *Shock* 2015 Apr;43(4):361–8. <https://doi.org/10.1097/SHK.0000000000000296>.
- [23] Gavala A, Myrianthefs P. Comparison of point-of-care versus central laboratory measurement of hematocrit, hemoglobin, and electrolyte concentrations. *Heart Lung* 2017 Jul–Aug;46(4):246–50. <https://doi.org/10.1016/j.hrtlng.2017.04.003> [Epub 2017 May 3].
- [24] Leino A, Kurvinen K. Interchangeability of blood gas, electrolyte and metabolite results measured with point-of-care, blood gas and core laboratory analyzers. *Clin Chem Lab Med* 2011;49:1187–91.
- [25] Solak Y. Comparison of serum sodium levels measured by blood gas analyzer and biochemistry autoanalyzer in patients with hyponatremia, eunatremia, and hypernatremia. *Am J Emerg Med* 2016 Aug;34(8):1473–9. <https://doi.org/10.1016/j.ajem.2016.04.037> [Epub 2016 Apr 29].
- [26] Mirzazadeh M, Morovat A, James T, Smith I, Kirby J, Shine B. Point-of-care testing of electrolytes and calcium using blood gas analysers: it is time we trusted the results. *Emerg Med J* 2016 Mar;33(3):181–6. <https://doi.org/10.1136/emermed-2015-204669> [Epub 2015 Sep 22].