The Agreement of Test Results Obtained by Blood Gas, Clinical Chemistry and Hematology Analyzer

Kan Gazı, Klinik Kimya ve Hemogram Analizörlerinden Elde Edilen Test Sonuçlarının Uyumu

Şerif Ercan[*] **Mahmut Çakır**[**]

[*] Lüleburgaz Devlet Hastanesi, Tıbbi Biyokimya, Kırklareli, Türkiye

[**] Lüleburgaz Devlet Hastanesi, Anesteziyoloji ve Reanimasyon Kliniği, Kırklareli, Türkiye

Başvuru Tarihi: 22.12.2017 **Kabul Tarihi:** 19.03.2018

ÖZET

Amaç: Analizörlerin farklı tiplerinin kullanımı ve örnek türündeki farklılıklar, test sonuçlarında farklılığa neden olabilmektedir. Bu çalışmada, konvansiyonel kan gazı analizörü sonuçları ile hasta başı kan gazı, klinik kimya ve hemogram analizörlerinden elde edilen sonuçların birbiri yerine kullanılabilirliğinin belirlenmesi amaçlandı.

Gereç ve Yöntem: Konvansiyonel (Radiometer ABL735) ve hasta başı kan gazı analizöründen (EPOC) elde edilen pH, pCO_2, pO_2, sodyum, potasyum, iyonize kalsiyum, glukoz, laktat ve hemoglobin sonuçları birbirleriyle karşılaştırıldı. Aynı zamanda, konvansiyonel kan gazı ve klinik kimya analizöründe (Cobas 6000 c501) ölçülen sodyum, potasyum ve glukoz sonuçları ile konvansiyonel kan gazı ve hemogram analizöründe (ABX Pentra 80) ölçülen hemoglobin sonuçları birbirleri ile karşılaştırıldı. Sonuçlar arasındaki uyum Bland-Altman yöntemi ile değerlendirildi.

Bulgular: Konvansiyonel ve hasta başı kan gazı analizörlerinden elde edilen pH, pO_2, sodyum, glukoz ve hemoglobin sonuçları arasındaki farklılık toplam izin verilen hatadan büyük bulundu. pCO_2 %95 uyum limitleri ise toplam izin verilen hata sınırlarına yakın idi. Konvansiyonel kan gazı ve klinik kimya analizörlerinde ölçülen sodyum ve potasyum sonuçlarının %95 uyum limitleri, toplam izin verilen hata sınırlarını aşmış olarak bulundu; buna karşın glukoz için uyum limitleri toplam izin verilen hata sınırlarına yakın belirlendi. Konvansiyonel kan gazı ve hemogram analizörlerinde ölçülen hemoglobin sonuçları arasında anlamlı farklılık tespit edilmedi.

Sonuç: Konvansiyonel ve hasta başı kan gazı analizörlerinden elde edilen test sonuçları arasında farklılıklar görülebilmektedir. Aynı zamanda, kan gazı analizörü ile klinik kimya analizörlerinde ölçülen testlerin sonuçları arasında da farklılıklara rastlanabilmektedir. Bu nedenle, test sonuçlarının hatalı

Yazışma adresi: Şerif Ercan
ORCID: https://orcid.org/0000-0001-9034-1404
Lüleburgaz Devlet Hastanesi Tıbbi Biyokimya Kırklareli, Türkiye
e-mail: serifercan@yahoo.com.tr

değerlendirilmesinin engellenmesi için, analizörlerin farklı türlerinde çalışılan testler arasındaki uyum belirlenmeli ve farklılık tespit edilen testlere ilişkin bilgi hasta sonuç raporlarında belirtilmelidir.

Anahtar Sözcükler: Elektrolitler, kan gazı analizi, glukoz, hemoglobin

ABSTRACT

Objective: The use of different types of analyzers and samples lead to obtaining different test results. This study aimed to investigate whether the test results yielded by conventional blood gas analyzer (cBGA) are considered interchangeable with those produced by point-of-care blood gas (pBGA), clinical chemistry (CCA), and hematology analyzers (HAA).

Material and Methods: pH, pCO_2, pO_2, sodium, potassium, ionized calcium, glucose, lactate, and hemoglobin values determined on the cBGA (Radiometer ABL735) were compared with those of pBGA (EPOC). Sodium, potassium, glucose, and hemoglobin levels obtained from the cBGA, CCA (Cobas 6000 c501), and HAA (ABX Pentra 80) were also compared with each other The agreement between the results obtained from two analyzers (pBGA vs. cBGA, cBGA vs. CCA, and cBGA vs. HAA) was assessed using the Bland-Altman method.

Results: The difference among pH, pO_2, sodium, glucose, and hemoglobin results obtained from the pBGA and cBGA were found to be greater than the total allowable error (TEa). The limits of agreement of the pCO_2 were close to the TEa limits. The 95% limits of agreement for sodium and potassium values yielded by cBGA and CCA were found to have exceeded the limits, whereas those of the glucose were close to the TEa limits. There was no significant bias between the hemoglobin values measured by the cBGA and HAA.

Conclusion: There may be differences between the test results obtained from conventional and point-of-care blood gas analyzers, as well as the test results measured in conventional blood gas and clinical chemistry analyzers. To avoid potential misinterpretations, tests analyzed on different types of devices and whose results are clinically different should be pointed out in patient result reports.

Keywords: Electrolytes, blood gas analysis, glucose, hemoglobin

INTRODUCTION

Blood gas testing is widely used to assess the oxygenation, ventilation, and acid-base status of patients admitted to operating rooms, emergency rooms, and intensive care units (1, 2).

A blood gas analysis can be performed by a blood gas analyzer in a central laboratory or by a point-of-care testing instrument near the patient. Compared to a central laboratory, a point-of- care testing has several advantages, such as a decreased total turnaround time, decreased pre-analytical laboratory errors (i.e. labeling, transport), and a decreased sample volume requirement (2-4). However, testing performed by poorly trained operators, a lack of satisfaction regarding the adequacy of analytical performance of testing instrument, the high cost, and difficulty of integrating test results into existing hospital information systems are major concerns (2-4).

The term "blood gas testing" traditionally refers to determining the partial pressures of the physiologically active gasses in blood (pO_2, pCO_2), the blood pH, and the oxygen saturation of the hemoglobin (3). Recently, the most of blood gas analyzers and point-of-care platforms have become simultaneously capable of performing the analysis of hemoglobin, electrolytes. (sodium, potassium, chloride, ionized calcium, and magnesium), glucose, and lactate (3).

In many medical center, blood gas is measured using a point-of-care system and a conventional blood gas analyzer, and the electrolytes, glucose, lactate, hemoglobin, and hematocrit levels are determined by the blood gas analyzers (point-of-care or conventional), routine clinical chemistry, and

routine hematology analyzers (3). However, blood gas, clinical chemistry, and hematology analyzers differ in analytical method, calibration, device technology, and type of sample (whole blood vs. plasma) (5). When using multiple analyzers, analyzer specific differences in accuracy and precision may be observed. These differences could lead to misinterpretations during diagnosis and particularly when monitoring.

This study was designed to investigate whether the test results obtained from conventional blood gas analyzer are considered interchangeable with those produced by point-of-care blood gas, clinical chemistry, and hematology analyzers.

MATERIAL AND METHODS

Sample collection and experimental design

A total of 150 patients who were admitted to the intensive care unit and the emergency department were enrolled in the study. A total of 194 arterial blood samples from 150 patients were drawn into blood gas syringes with electrolyte-balanced heparin (Radiometer Medical ApS, Brønshøj, Denmark) by the physician.

The study was based on pre-existing samples whose the routine analysis was completed. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Instead of liquid heparin, lyophilized heparin was used to prevent the dilution effects of heparin (6). To eliminate pre-analytical errors, air exposure to the samples was minimized and the samples were properly mixed before the aspiration of the blood gas analyzers. If air bubbles formed, they were immediately expelled. In addition, clotted samples were excluded.

Blood samples were first analyzed on the Radiometer ABL735 (cBGA) blood gas analyzer (Radiometer Medical ApS, Brønshøj, Denmark) and thereafter on the Enterprise Point of Care Blood Analysis System (pBGA) (Epocal Inc, Ottawa, Canada). After the blood gas analysis, the samples were run on the ABX Pentra 80 (HAA) (Horiba Medical, Montpellier, France) hematology analyzer to determine the hemoglobin and the hematocrit values. Following this, the remaining samples were centrifuged at 1000*g* for 10 min to obtain plasma samples. In the plasma samples, the sodium, potassium, and glucose values were measured on the Cobas 6000 c501 analyzer (CCA) (Roche Diagnostic GmbH, Mannheim, Germany). Hemolysis can affect the potassium results, even if it is not visible. Therefore, the hemolysis index (HI) values of the plasma samples were determined to detect hemolysis. The samples with HI of above 90 were excluded from the study on potassium. The cut-off value of HI for sodium and glucose was 1000 (7).

Analytical methods

pH, pCO_2, sodium, potassium, and ionized calcium values were determined by the potentiometric measuring principle on the cBGA and pBGA, while the pO_2, glucose, and lactate values were measured amperometrically. The concentration of the total hemoglobin was analyzed by spectrophotometrically on the cBGA, and then the hematocrit was calculated by multiplying it by a constant. However, on the pBGA, the hematocrit values were determined conductometrically before the hemoglobin values were calculated.

The hemoglobin was analyzed spectrophotometrically on the HAA. The hematocrit was calculated directly from the red blood cell histogram measured by an electronic impedance variation principle.

The glucose (enzymatic method, hexokinase), potassium (indirect method using ion-selective electrodes), and sodium (indirect method using ion-selective electrodes) were analyzed on the CCA by the methods

indicated in the above parentheses. The HI was automatically estimated using a bichromatic wavelength paired measurement at 570 and 600 nm on the CCA.

Precision was assessed by running control samples at two levels during study period. The coefficients of variations (CV) were calculated for analytes measured on cBGA, CCA and HAA. CV values for tests measured on pBGA were not obtained because aqueous control samples have been only performed with each new box of cartridges.

Statistical analysis

All statistical analyses were performed using MedCalc Statistical Software version 14.8.1 (MedCalc Software bvba, Ostend, Belgium) and the Statistical Package for Social Sciences (SPSS 15.0, SPSS Inc., Chicago, IL).

The agreement between the test results obtained from the two analyzers (pBGA vs. cBGA, cBGA vs. CCA, and cBGA vs. HAA) was assessed using the Bland-Altman method. It was determined whether the upper and lower limits of agreement were within the total allowable error (TEa) based on the Clinical Laboratory Improvement Amendments (CLIA) criteria (for pH, pCO_2, sodium, potassium, glucose, hemoglobin, and hematocrit) (8). For the ionized calcium and lactate, the TEa values based on the biological variation (9) were used because there are not the specifications for allowable total error based on CLIA. For the pO_2, evaluation was done according to ±10% considering test specifications recommended by Guidelines of the German Federal Medical Council (RiliBÄK) (10) and the allowable error limit used in the previous study (6).

In addition to the Bland-Altman plots, the results from other statistical analysis including paired Student's t-test, the Wilcoxon signed ranks, and the Deming regression analysis was also reported. The Kolmogorov-Smirnov test was used to determine whether data distribution was normal or not. P values less than 0.05 were considered to be statistically significant.

RESULTS

By running control samples at two levels, CV values for all analytes measured on ABL735 (n=40), Cobas c501 (n=40) and Pentra 80 (n=21) analyzers were calculated as below 3%, except lactate. The CV of lactate was 5.2% at high level control sample.

The comparison of results yielded by pBGA and cBGA:

A total of 35 whole blood samples were analyzed on the pBGA and cBGA. The maximum delay in introducing samples from the cBGA to the pBGA was 10 mins.

The mean difference, 95% limits of agreement, correlation coefficient, intercept, and slope values among test results obtained from the pBGA and cBGA are illustrated in Table I.

When compared pH, pCO_2, ionized calcium, glucose, lactate, sodium, potassium, and hemoglobin results obtained by cBGA and pBGA, 95% limits of agreement for pH, pO_2, glucose, sodium, and hemoglobin were found to have exceeded the TEa limits. However, the 95% limits of agreement for the potassium, ionized calcium, and lactate were within the TEa limits and those of the pCO_2 were close to the TEa limits.

When compared to the cBGA, it was found that test results measured on the pBGA were significantly different in the paired statistical analysis, with the exception of the glucose and lactate ($p<0.001$). However, there was a significant correlation between the cBGA and the pBGA. The correlation coefficient was ranged from 0.86 to 0.99 ($p<0.001$).

In the Deming regression analysis, a constant bias was detected between the two analyzers for the pO_2, whereas a proportional bias was determined for the pCO_2. In addition, there was both a constant and proportional bias for the pH. For the remaining tests, no significant measurement bias was detected with the Deming regression analysis.

Table 1. The Comparison of the test results obtained by the point-of-care and the conventional blood gas analyzer

Analytes	cBGA Mean ± SD (n=35)	pBGA Mean ± SD (n=35)	[a]Mean Difference (95% CI)	[b]Correlation Coefficient (r)	Limits of Total Allowable Error	Limits of Agreement of Difference	Sample numbers surpassed limits of total allowable error	Deming Regression Analysis: Intercept (95% CI)	Deming Regression Analysis: Slope (95% CI)
pH	7.35±0.20	7.33±0.21	0.02* (0.02-0.03)	0.99*	0.04	-0.01 to 0.07	20%	-0.49 (-0.72 to -0.25)	1.06 (1.03 to 1.09)
pCO_2 (kPa)	5.78±2.03	6.13±2.16	-0.35* (-0.44 to -0.25)	0.99*	0.7 kPa	-0.87 to 0.18	6.25%	-0.03 (-0.33 to 0.25)	1.06 (1.01 to 1.12)
pO_2 (kPa)	11.90±8.08	12.85±8.43	-0.95* (-1.15 to -0.75)	0.99*	10%	-2.02 to 0.12	30%	0.45 (0.02 to 0.87)	1.04 (0.99 to 1.08)
Ionized Calcium (mmol/L)	1.11±0.07	1.14±0.08	-0.03* (-0.05 to -0.02)	0.86*	2%	-0.11 to 0.05	0%	-0.18 (-0.51 to 0.15)	1.20 (0.90 to 1.49)
Lactate (mmol/L)	3.40±4.20	3.25±4.10	0.15** (-0.18 to 0.49)	0.99*	30.4%	-1.7 to 2	3.03%	-0.07 (-0.88 to 0.74)	0.98 (0.61 to 1.34)
Sodium (mmol/L)	133.8±3.04	138.5±3.47	-4.7* (-5.53 to -3.89)	0.74*	4 mmol/L	0 to -0.94	57.1%	-19.38 (-53.16 to 14.39)	1.18 (0.92 to 1.43)
Potassium (mmol/L)	4.12±0.7	4.3±0.79	-0.18* (-0.21 to -0.12)	0.99*	0.5 mmol/L	-0.44 to 0.1	0%	-0.39 (-0.58 to -0.20)	1.13 (1.09 to 1.18)
Glucose (mmol/L)	10.04±7.13	10.31±7.57	-0.27** (-0.54 to 0.18)	0.99*	10%	-1.8 to 1.27	12.4%	-0.36 (-1.34 to 0.61)	1.06 (0.94 to 1.18)
Hemoglobin (g/L)	116.9±18.3	134.8±20.6	-17.9* (-21.5 to -14.3)	0.86*	7%	-38.4 to 2.5	76.4%	3.93 (-26.67 to 34.53)	1.12 (0.86 to 1.38)

[a] The difference of test results obtained from the pBGA and the cBGA were statistically evaluated by paired t test (for all tests except lactate) or Wilcoxon signed ranks test (for lactate) according to the data distribution (* $p<0.001$,**Not significant). [b] Correlation coefficients (r) were calculated by Pearson (for all tests except lactate) or Spearman (for lactate) correlation analysis according to the data distribution (* $p<0.001$). CI: Confidence interval, SD: Standard Deviation, cBGA: Conventional blood gas analyzer (Radiometer ABL735), pBGA: Point of care blood gas analyzer (Enterprise Point of Care)

The comparison of results yielded by cBGA and CCA:

A total of 194 samples were analyzed to evaluate the agreement of test results between the cBGA and the CCA. After being measured on the cBGA, samples were analyzed within an average time of 47 minutes (from 15 minutes to 2 hours). During the comparison of the potassium results, 16 samples with hemolysis index of greater than 90 were excluded from the study.

The mean difference, 95% limits of agreement, correlation coefficient, intercept, and slope values among the test results obtained from the cBGA and CCA are shown in Table II.

When the upper and lower limits of agreement were tested to be within the TEa limits, sodium and potassium values were found to have exceeded the limits, whereas the glucose was close to the TEa limits.

In the paired statistical analysis, it was observed that there was a significant difference between the glucose, sodium, and potassium measured on the cBGA and CCA ($p<0.001$). The correlation coefficients between the glucose and potassium results obtained from two analyzers were high, ranged from 0.98-0.99 ($p<0.001$). However, the correlation coefficient for sodium was calculated as 0.72 ($p<0.001$).

In the Deming regression analysis, for all tests, the proportional bias was determined between two analyzers. In addition, there was a constant bias between sodium and glucose results.

The comparison of results yielded by cBGA and HAA:

A total of 44 samples were analyzed on the cBGA and HAA to compare the hemoglobin and hematocrit values.

The mean difference, 95% limits of agreement, correlation coefficient, intercept, and slope values among the test results obtained from the cBGA and HAA are provided in Table III.

During the analysis of Bland-Altman plots, the 95% limits of agreement for the hemoglobin values were found to be within the CLIA TEa, and those of the hematocrit were close to the TEa limits.

In the paired statistical analysis, there was no difference between the cBGA and HAA for the hematocrit, whereas the hemoglobin values were significantly different ($p<0.001$). Furthermore, a significant correlation was determined for both the hemoglobin and hematocrit between the two analyzers ($r=0.98$, $p<0.001$).

For both the hemoglobin and hematocrit, no significant measurement bias was detected by the Deming regression analysis.

DISCUSSION

In any medical center, if an analyte is measured by using different types of devices, the knowing the possible difference between results obtained from these measurement devices is crucial for accurate diagnosis and monitoring. The present study provides data regarding agreement between test results obtained from cBGA and those of pBGA, CCA and HAA.

In the study, when the pH, pCO_2, ionized calcium, glucose, lactate, sodium, potassium, and hemoglobin results obtained from cBGA were compared with those of pBGA, only the pCO_2, potassium, ionized calcium and lactate results were found to be interchangeable.

Koninck et al. (11) compared four cartridge-type blood gas analyzers with a traditional blood gas analyzer for pH, pO_2, pCO_2, ionized calcium, potassium, glucose, lactate, and hemoglobin. They reported that the test results obtained from cartridge–type BGAs might be significantly different from those of traditional BGA (11). In another study, Leino et al. (6) compared pH, pCO_2, pO_2, and ionized calcium results obtained from a pBGA and cBGA. They have demonstrated

Table 2. The comparison of sodium, potassium, and glucose results obtained by the conventional blood gas and the clinical chemistry analyzer

Analytes	cBGA Mean ± SD (n=194)	CCA Mean ± SD (n=194)	[a]Mean Difference (95% CI)	[b] Correlation coefficient (r)	Limits of Total Allowable Error	Limits of Agreement of Difference	Sample numbers surpassed limits of total allowable error	Deming Regression Analysis: Intercept (95% CI)	Deming Regression Analysis: Slope (95% CI)
Sodium (mmol/L)	130.6±7.5	138.8±6.8	-8.2* (-8.8 to -7.6)	0.72*	4 mmol/L	0.1 to 16.3	78.3%	-27.33 (-44.56 to -10.10)	1.14 (1.01 to 1.26)
Potassium (mmol/L)	3.8±0.9	4.2±1.0	-0.4* (-0.42 to -0.36)	0.98*	0.5 mmol/L	0.02 to 0.77	26.9%	0.07 (-0.02 to 0.17)	0.89 (0.86 to 0.91)
Glucose (mmol/L)	9.0±5.0	9.3±7.6	-0.3** (-0.36 to -0.13)	0.99*	10%	-1.4 to 1.9	5.3%	0.08 (0.60 to 1.17)	0.88 (0.84 to 0.91)

[a] The difference of test results obtained from pBGA and cBGA were statistically evaluated by paired t test (for potassium) or Wilcoxon signed ranks test (for sodium and glucose) according to the data distribution (* $p<0.001$,**$p<0.01$). [b]Correlation coefficient was calculated by Pearson (for potassium) or Spearman (for sodium and glucose) correlation analysis according to the data distribution (* $p<0.001$). CI: Confidence interval, SD: Standard Deviation, cBGA: Conventional blood gas analyzer (Radiometer ABL735), CCA: Clinical chemistry analyzer (Cobas c501)

Table 3. The comparison of the hematocrit and hemoglobin results obtained by the conventional blood gas and the automated hematology analyzer

Analytes	cBGA Mean ± SD (n=44)	HAA Mean ± SD (n=44)	[a]Mean Difference (95% CI)	[b] Correlation coefficient (r)	Limits of Total Allowable Error	Limits of Agreement of Difference	Sample numbers surpassed limits of total allowable error	Deming Regression Analysis: Intercept (95% CI)	Deming Regression Analysis: Slope (95% CI)
Hematocrit (%)	39.1±6.7	39.1±6.4	0* (-0.38 to 0.43)	0.98*	6%	-2.6 to 2.7	6.8%	1.95 (-0.62 to 4.51)	0.95 (0.88 to 1.01)
Hemoglobin (g/L)	127.3±22.3	130.9±22.9	-3.6** (-4.9 to -2.2)	0.98*	7%	-12.4 to 5.2	4.5%	-0.29 (-6.62 to 6.04)	1.03 (0.98 to 1.08)

[a] The difference of hematocrit and hemoglobin results obtained from cBGA and HAA were statistically evaluated by paired t test (*$p<0.001$,**Non significant). [b] Correlation coefficients were calculated by Pearson correlation analysis (* $p<0.001$). CI: Confidence interval, SD: Standard Deviation, cBGA: Conventional blood gas analyzer (Radiometer ABL735), HAA: Automated hematology analyzer (ABX Pentra 120)

that the results obtained from a pBGA and cBGA were interchangeable. However, Thomas et al. (12) found only the pCO_2 to be interchangeable.

It appears that the use of interchangeable of test results obtained from a pBGA and cBGA are dependent on the analyte measured and the type of analyzer. In any hospital, before a point-of-care and conventional blood gas analyzer are used to measure blood gas and other analytes, the agreement between the results produced by the two types of analyzers should be determined. In this context, the best of our knowledge, the study provides first data regarding the agreement between test results obtained by ABL700 and EPOC blood gas analyzers.

In our study, the sodium and potassium levels obtained by the conventional BGA were found to be significantly lower than those of the clinical chemistry analyzer. In support of our findings, in previous studies, it has been reported that the sodium values were not considered interchangeable between the BGA and CCA (6, 13-17).

However, the different findings about the agreement between potassium results obtained from the BGA and CCA have been reported in previous studies (6, 13-18). Similar to our findings, using the Bland-Altman plots and the CLIA TEa limits, few studies (14, 15, 17) reported that there was a clinically meaningful difference between the BGA and CCA for potassium results. On the contrary, other studies (6, 13, 16, 18) stated that the difference between the potassium values obtained from BGA and CCA was negligible. Generally, a regression and correlation analysis, as well as the mean difference, has been performed to determine the agreement between the potassium results. In the present study, the Deming regression yielded slopes of 0.89 and an intercept of 0.07 for the potassium. In addition, the correlation coefficient was found to be 0.98. The mean difference of the potassium values obtained from the BGA and CCA was also within the CLIA TEa limits. However, the Bland-Altman difference plots showed wide limits of agreement for the potassium so that 48 of 178 (26.9%) paired samples fell out of the CLIA TEa limits. For comparison, the 95% limits of agreement for potassium were unfortunately not obtained by these studies, except the study by Jose et al. (18). Accordingly, the difference in the statistical method selected to determine the agreement among the test results obtained from different analyzers might be a reason of obtaining different conclusions. We used the Bland-Altman limit of agreement to determine the use of interchangeable test results because it is considered the best statistical test to compare two different measuring devices (19, 20). However, in spite of performing the Bland-Altman plots, Jose et al. (18) have stated that the 95% limits of agreement were within the CLIA TEa limits for potassium. This might arise from the actual differences in the electrode activity.

In previous studies (6, 13, 14, 16), the difference in the sodium and potassium results measured on the BGA and CCA have been attributed to the use of a different ion selective electrode technology for determining the sodium and potassium levels. A direct ion selective electrode is used by BGA while CCA uses an indirect ion selective electrode. In a recent study, Dimeski et al. (21) reported that an important disagreement between indirect and direct ISE sodium measurements might exist. They also concluded that the main problem is that indirect ISE technology is prone to an overestimation associated with hypoproteinemia, especially in specimens from intensive care unit (21).

In addition, sodium, potassium and glucose levels were measured using a whole blood sample on a blood gas analyzer, whereas plasma or serum samples are used by a clinical chemistry analyzer. It is well known that sodium, potassium and glucose are confined to the water phase. Since water is excluded by blood cells, a whole blood sample has less water phase than a plasma sample in a fixed volume (22). Sodium,

potassium and glucose levels might be therefore lower in whole blood samples compared to plasma or serum samples.

Previously, it was reported that strict maintenance of normoglycemia by insulin therapy reduced the mortality and morbidity of intensive care unit adults and pediatric patients (23, 24). Therefore, it is important whether glucose results obtained by different methods are interchangeable. In the present study, for glucose, the 95% limits of agreement were close to the TEa limits. Similarly, previous studies (6, 16, 25) have reported a clinically acceptable difference in glucose results between the BGA and CCA. Finally, in our study, it was determined that the hemoglobin and hematocrit results obtained from BGA and HAA was considered interchangeable. In accordance with our study, Leino et al. (6) and Zhang et al. (17) have shown that there was no statistical difference between the conventional BGA and HAA for hemoglobin values.

In conclusion, the difference among potassium, ionized calcium, lactate, and pCO_2 results obtained from the pBGA and cBGA are within the clinically acceptable limits. The variability in the measurement of glucose values between the cBGA and CCA is negligible. However, sodium and potassium results yielded by the cBGA and CCA are not considered interchangeable. In addition, there is an acceptable bias between the cBGA and HAA for hemoglobin. To avoid potential misinterpretations, clinicians should be informed that different types of devices may yield different results for same test parameter. For this purpose, the info about tests whose results are varying among different types of devices might be denoted in patient result reports.

Acknowledgments

We thank Süreyya Çakır, Nazan Hoşgör, Kader Üstüntaş Köse, Ercan Güneş, İlhan Şevik and Yalçın Beyreli for technical assistance.

REFERENCES

1. Davis MD, Walsh BK, Sittig SE, Restrepo RD. AARC clinical practice guideline: blood gas analysis and hemoximetry. Respir Care 2013;58(10):1694-703.
2. Kapoor D, Srivastava M, Singh P. Point of care blood gases with electrolytes and lactates in adult emergencies. Int J Crit Illn Inj Sci 2014;4(3):216-22.
3. Baird G. Preanalytical considerations in blood gas analysis. Biochem Med 2013;23(1):19-27.
4. D'Orazio P, Fogh-Andersen N, Okorodudu A, Shipp G, Shirey T, Toffaletti J. Critical care. In: Nichols JH, eds. Evidence-Based Practice for Point-of-Care Testing. 1st ed. Washington: The National Academy of Clinical Biochemistry, 2006. p. 465-78.
5. 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(7):1187-91.
6. CLSI. Blood gas and ph analysis and related measurements; approved guideline - second edition. Vol. CLSI Document C46-A2. Wayne, PA: Clinical and Laboratory Standards Institute, 2010.
7. List of interferences based on serum indices for serum and plasma (not applicable for urine). F. Hoffmann-La Roche Ltd. Available from: http://www.roche-diagnostics.ch/content /dam/ corporate/roche-dia_ch/documents/ serumindices/ Interferences_cobas_c311_ c501_c502.pdf (Last accessed: January 2015)
8. Limet K, Boyd JC. Selection and analytical evaluation of methods-with statistical techniques. In: Burtis CA, Ashwood ER, Bruns DE, eds. Tietzt textbook of clinical chemistry and molecular diagnostic. 4th ed. Philadelphia: Elsevier Saunders Inc; 2006. p. 353-403.
9. Desirable specifications for total error, imprecision and bias, derived from intra- and inter-individual biologic variation. Westgard QC. Available from: https://www.westgard.com /biodatabase1.htm. (Last accessed: January 2015)
10. Rilibak - German Guidelines for Quality. Westgard QC. Available from: https://www.westgard.com/ rilibak.htm. (Last accessed: June 2015)

11. De Koninck AS, De Decker K, Van Bocxlaer J, Meeus P, Van Hoovels L. Analytical performance evaluation of four cartridge-type blood gas analyzers. Clin Chem Lab Med 2012;50(6):1083-91.

12. Thomas FO, Hoffman TL, Handrahan DL, Crapo RO, Snow G. The measure of treatment agreement between portable and laboratory blood gas measurements in guiding protocol-driven ventilator management. J Trauma 2009;67(2):303-13.

13. 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.

14. 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.

15. Chhapola V, Kanwal SK, Sharma R, Kumar V. A comparative study on reliability of point of care sodium and potassium estimation in a pediatric intensive care unit. Indian J Pediatr 2013;80(9):731-5.

16. Uyanik M, Sertoglu E, Kayadibi H, Tapan S, Serdar MA, Bilgi C, Kurt I. 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(2):97-105.

17. Zhang JB, Lin J, Zhao XD. Analysis of bias in measurements of potassium, sodium and hemoglobin by an emergency department-based blood gas analyzer relative to hospital laboratory autoanalyzer results. PLoS One 2015;10(4):e0122383

18. José RJ, Preller J. Near-patient testing of potassium levels using arterial blood gas analysers: can we trust these results? Emerg Med J 2008;25(8):510-3.

19. Bland JM, Altman DG. Statistical method for assessing agreement between two methods of clinical measurement. Lancet 1986; 1(8476):307-10.

20. Giavarina D. Understanding Bland Altman analysis. Biochem Med 2015;25(2):141–51.

21. Dimeski G, Morgan TJ, Presneill JJ, Venkatesh B. Disagreement between ion selective electrode direct and indirect sodium measurements: estimation of the problem in a tertiary referral hospital. J Crit Care 2012;27(3):9-16.

22. Scott MG, LeGrys VA, Klutts JS. Electrolytes and blood gases. In: Burtis CA, Ashwood ER, Bruns DE, eds. Tietz textbook of clinical chemistry and molecular diagnostic. 4th ed. Philadelphia: Elsevier Saunders Inc; 2006.p. 983-1014.

23. Vlasselaers D, Milants I, Desmet L, Wouters PJ, Vanhorebeek I, van den Heuvel et al. Intensive insulin therapy for patients in paediatric intensive care: a prospective, randomised controlled study. Lancet 2009;373(9663):547-56.

24. van den Berghe G, Wouters P, Weekers F, Verwaest C, Bruyninckx F, Schetz M et al. Intensive insulin therapy in critically ill patients. N Engl J Med 2001;345(19):1359-67.

25. Poesen K, De Prins M, Van den Berghe G, Van Eldere J, Vanstapel F. Performance of cassette-based blood gas analyzers to monitor blood glucose and lactate levels in a surgical intensive care setting. Clin Chem Lab Med 2013;51(7):1417-27.