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ORIGINAL ARTICLE

Evaluation of the Analytical Performance of the Modified Enterprise Point-of-Care Blood Gas and Electrolyte Analyzer in a Pediatric Hospital

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Abstract: Arterial blood gas testing is an essential component that directs the evaluation of a patient's general condition, especially in the emergent setting. We evaluated the analytical performance of the modified Enterprise point-of-care (EPOC) blood gas and electrolyte analyzer system with respect to precision and accuracy and compared our results with those obtained using the point-of-care i-STAT method and the criterion standard ABL 835 Radiometer blood gas analyzer in a pediatric hospital. Evaluation studies were performed as per the Clinical Laboratory Standards Institute guidelines and included intra-assay and interassay precision and accuracy, linearity, and concordance analyses with i-STAT and ABL 835 Radiometer. Intra-assay and interassay coefficient of variation for each analyte was calculated and was less than 6% for all analytes in the ranges tested including pH, Po_2, Pco_2, Na^+, K^+, Ca^{2+}, glucose, lactate, and hematocrit, Cl^-, and creatinine. All of the analytes were linear across the reportable range. For the methods comparison of EPOC system with the i-STAT method, using 40 samples, the correlation coefficients were $r > 0.94$ for all analytes with the exception of Ca^{2+} ($r = 0.61$).

For the methods comparison of EPOC system with the criterion standard ABL 835 Radiometer on 40 samples, the correlation coefficients were higher than 0.97 for all analytes with the exception of hematocrit and hemoglobin ($r = 0.8$). Thus, in our pediatric hospital setting, the EPOC system showed excellent precision and accuracy and compared favorably with the i-STAT and ABL 835 Radiometer assay results. These findings, together with the low cost, room temperature storage of test cards and availability of metabolites such as lactate, glucose, and creatinine along with the wireless connectivity of the EPOC system, provide an operational advantage over other point-of-care blood gas analyzers currently available.

Key Words: EPOC, blood gas, point of care, electrolyte, evaluation

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The growing complexities of hospital laboratory infrastructure and the time-sensitive nature of turnaround time (TAT) for many critical laboratory test results have necessitated the evolution of many point-of-care (POC) laboratory assays.

A rapid TAT is of particular importance in the intensive care setting of many hospitals including pediatric hospitals where the provision of critical laboratory values helps guide patient management.

Arterial blood gas and electrolyte testing is an essential component that directs the evaluation of a patient's general condition in the clinical setting.[1] Although most conventional benchtop analyzers are large and untransportable and involve samples being brought to the laboratory, these increase TAT.[2] Quick analysis is preferable especially in emergency situations. The most significant aspect of any POC device is the accuracy and precision of laboratory values when compared with conventional or criterion standard methods. This is true because concerns about analytical performance and reliability of results of POC instruments still exist.[3]

The last few decades or so has seen the development of many different POC analyzers for various laboratory tests such as electrolytes, blood gases, and other metabolites.

Historically, the POC blood gas and electrolyte testing market has been dominated by the i-STAT instruments in the United States.[4–6] In 2006, the US Food and Drug Administration approved the Enterprise point-of-care (EPOC) blood gas and electrolyte analysis system (Alere, Waltham, Mass) as a portable blood gas and electrolyte analyzer.[7] Although both hand-held clinical analyzers measure many of the same laboratory values, the newer modified EPOC system has certain advantages over both the i-STAT POC analyzer and the conventional ABL radiometer. We performed an evaluation of the analytical performance of the EPOC hand-held blood gas analyzer in our pediatric hospital from 2011 to 2013 and performed a concordance analysis with the POC, i-STAT blood gas analyzer and conventional ABL radiometer.

MATERIALS AND METHODS

Texas Children's Hospital performed an analytical and performance evaluation of the EPOC system blood gases, electrolytes, glucose, lactate, creatinine, and hematocrit assays from December 2011 to February 2013. Evaluation studies were performed as per the Clinical Laboratory Standards Institute guidelines.

Intra-assay (within-run) precision studies were performed for all the analytes, which included pH, Pco_2, and Po_2, Na^+, K^+, Cl^-, Ca^{2+}, glucose (Glu), creatinine (Creat), hematocrit (Hct), and lactate. Three different levels of samples with $n = 10$ were run in duplicates. Interassay (between-day) precision studies were also conducted 2 times per day for 2.5 days for the previously mentioned analytes with $n = 10$ samples each. Accuracy and linearity studies were also performed on all the analytes (pH, Pco_2, and Po_2, Na^+, K^+, Cl^-, Ca^{2+}, Glu, Creat, Hct, and lactate) across the reportable range of the analytes. We also conducted the reader-to-reader comparison studies on randomly selected instruments ($n = 8$). Correlation studies were performed on 40 samples on EPOC, i-STAT, and ABL 835 Radiometer blood gas and electrolyte analyzers. The whole blood samples were first run on ABL 835 Radiometer and then on EPOC and i-STAT analyzers simultaneously.

General Methods

The EPOC blood gas and electrolyte analyzer is a hand-held portable device, weighing approximately 500 g with the provision of single-use test cards, which are stored at room temperature. The analyzer is based on the principles of potentiometry, amperometry,

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TABLE 1A. Intra-assay Precision

Analyte	Sample	Mean	SD	%CV
Calcium (n = 10), mg/dL	1	1.47	0.015	1.0
	2	0.66	0.006	1.0
	3	1.11	0.013	1.2
Glucose (n = 10), mg/dL	1	40.5	0.5	1.3
	2	105.2	0.6	0.6
	3	331.7	10.6	3.2
Hematocrit (n = 10), %	1	19.3	0.5	2.5
	2	31.7	0.5	1.5
	3	47.0	0.0	0.0
K^+ (n = 10), mmol/L	1	2.05	0.05	2.6
	2	3.99	0.03	0.8
	3	5.90	0.00	0.0
Lactate (n = 10), mmol/L	1	0.97	0.021	2.1
	2	2.91	0.059	2.0
	3	6.08	0.129	2.1
Na^+ (n = 10), mmol/L	1	112.1	1.1	1.0
	2	161.3	0.7	0.4
	3	137.6	0.7	0.5
PCO_2 (n = 10), mm Hg	1	72.60	1.56	2.1
	2	37.87	0.44	1.2
	3	21.31	0.45	2.1
pH (n = 10)	1	7.038	0.013	0.2
	2	7.386	0.002	0.0
	3	7.419	0.009	0.1
PO_2 (n = 10), mm Hg	1	64.64	4.12	6.4
	2	101.34	3.85	3.8
	3	123.72	8.45	6.8
Chloride (n = 10), mmol/L	1	76.0	1.054	1.39
	2	123.0	1.663	1.35
	3	101.0	0.823	0.81
Creatinine (n = 10), mg/dL	1	0.9	0.036	3.95
	2	4.2	0.104	1.35
	3	5.39	0.167	3.10

and conductometry. Each test card provides results of 11 analytes and certain calculated parameters: pH, PCO_2, and PO_2, Na^+, K^+, Cl^-, Ca^{2+}, Glu, Creat, Hct, and lactate. In addition, it also gives certain calculated parameters: bicarbonate, total carbon dioxide, base excess (ecf), base excess (b), calculated oxygen saturation, and calculated hemoglobin. Every test card is bar coded with lot number and expiration date. The system requires 95 μL of fresh, whole heparinized blood. The device autoscans the test card barcode and patient ID and securely transmits this information in real time through wireless connectivity to a computer database. The system is interfaced with the laboratory information systems/hospital information systems. Results are reported in less than 30 seconds. The system uses AC adaptor and/or rechargeable batteries. Each test card is discarded after single use.

The ABL 835 Radiometer is a benchtop blood gas analyzer that is conventionally used as the criterion standard method for the measurement of blood gases. The ABL 835 Radiometer can measure analytes including pH, PCO_2, PO_2, Na^+, K^+, Cl^-, Ca^{2+}, Hct and hemoglobin (Hb). The minimum sample volume required is 95 μL with capillary mode and has a TAT of approximately 1 minute. Because creatinine is not available on ABL 835 Radiometer for correlation with EPOC, these results were compared with the Vitros 5600.

The i-STAT blood gas analyzer is a portable hand-held point-of-care blood gas analyzer used for the measurement of whole blood gases (pH, PCO_2, and PO_2) and electrolytes (Na^+, K^+, and ionized calcium (iCa^{2+})). The system uses a disposable cartridge containing an impregnated biosensor for each analyte. Metabolites, creatinine and lactate, can be analyzed using separate cartridges for each one in addition to blood gas and electrolytes. The minimum sample size is 95 μL and the TAT from sample introduction to result availability is approximately 2 minutes.

Statistics

Analytical and concordance analysis was performed on 40 samples that were dropped off in the Texas Children's Clinical Laboratory for routine clinical care. Regression analysis was performed using the methods comparison data. For the purpose of this analysis, assay values above or below their respective reportable ranges were removed from the analytical correlation. This was done because discrete values are required for the regression analysis that is used to determine the analytical correlation and it is not possible to accurately estimate a value for specimen outside the reportable range. These values were included in the concordance study because that is a qualitative analysis. If the 2 assays were either both above, below, or within the analyte-specific reference ranges, they were concordant.

RESULTS

Both intra-assay and interassay precision studies were performed in replicates of n = 10. Intra-assay precision studies were conducted for various analytes as shown in Table 1A. For iCa^{2+}, Hct, Na^+, K^+, Cl^-, and pH, at least 3 samples (low, medium, and high levels) (n = 10) were analyzed and percent of coefficient of variation (%CV) was less than 1%; for glucose (n = 10), 3 different levels were analyzed with a %CV of less than 5%; for lactate (n = 10), all the 3 sample types had a %CV of 2.0; for PCO_2

TABLE 1B. Interassay Precision

Analyte	Sample	Mean	SD	%CV
iCalcium (n = 10), mmol/L	1	1.52	0.020	1.30
	2	0.67	0.008	1.16
Glucose (n = 10), mg/dL	1	35.1	1.140	3.25
	2	246.8	5.608	2.27
Hematocrit (n = 10), %	1	20.0	0.000	0.00
	2	46.9	0.354	0.75
K^+ (n = 10), mmol/L	1	2.11	0.032	1.50
	2	6.17	0.063	1.03
Lactate (n = 10), mmol/L	1	0.85	0.019	2.17
	2	5.72	0.084	1.47
Na^+ (n = 10), mmol/L	1	110.2	0.775	0.70
	2	161.9	1.000	0.62
PCO_2 (n = 10), mm Hg	1	69.61	2.733	3.93
	2	21.61	0.403	1.87
pH (n = 10)	1	7.030	0.023	0.32
	2	7.620	0.011	0.15
PO_2 (n = 10), mm Hg	1	66.68	2.411	3.62
	2	175.03	2.932	1.67
Creatinine (n = 10), mg/dL	1	0.90	0.020	2.19
	2	4.32	0.008	0.18
Chloride (n = 10), mmol/L	1	75.85	0.822	1.02
	2	123.9	1.000	0.81

TABLE 2. Accuracy Study

	Assigned	Range	Value
pH			
Sample 1	7.046	6.996–7.096	7.031
Sample 2	7.390	7.340–7.440	7.384
Sample 3	7.648	7.598–7.698	7.639
P_{CO_2}, mmHg			
Sample 1	37.7	33.7–41.7	37.9
Sample 2	21.3	17.3–25.3	21.2
Sample 3	71.3	62.7–17.3	69.4
P_{O_2}, mm Hg			
Sample 1	66.5	51.5–81.5	69.3
Sample 2	103.6	88.1–119.1	101.4
Sample 3	30.9	15.9–45.9	30.9
Na^+, mmol/L			
Sample 1	113.0	108.0–118.0	113.0
Sample 2	139.0	134.0–144.0	139.0
Sample 3	162.0	157.0–167.0	161.0
K^+, mmol/L			
Sample 1	2.0	1.6–2.4	2.1
Sample 2	3.9	3.5–4.3	4.0
Sample 3	7.3	6.8–7.8	7.3
iCa^{2+}, mmol/L			
Sample 1	1.5	1.4–2.6	1.5
Sample 2	0.7	0.6–0.7	0.7
Sample 3	3.6	3.2–4.0	3.5
Glucose, mg/dL			
Sample 1	41.0	32.0–50.0	41.0
Sample 2	106.0	91.0–121.0	105.0
Sample 3	647.0	505.0–789.0	593.0
Lactate, mmol/L			
Sample 1	0.95	0.65–1.25	0.97
Sample 2	2.87	2.2–3.52	3.01
Sample 3	5.94	4.60–7.08	6.23
Hct, %			
Sample 1	19.0	16.0–22.0	19.0
Sample 2	47.0	43.0–51.0	47.0
Sample 3	32.0	29.0–35.0	32.0
Chloride, mmol/L			
Sample 1	74	69–79	76
Sample 2	122	114–130	124
Sample 3	141	127–155	143
Creatinine, mg/dL			
Sample 1	0.85	0.40–1.30	0.8
Sample 2	4.43	3.44–5.42	4.4
Sample 3	2.02	1.57–2.47	2.1

(n = 10), all the 3 sample levels showed a %CV of approximately 1.2% to 2.0%; for P_{O_2} (n = 10), the %CV was 6% for all the 3 levels of samples. For creatinine (n = 10), the %CV was less than 5% for all the 3 samples analyzed.

Interassay precision studies were also conducted 2 times per day for 2.5 days as shown in Table 1B. The %CV for iCa^{2+} (n = 10), glucose (n = 10), Hct (n = 10), K^+ (n = 10), Na^+ (n = 10), Cl^- (n = 10), lactate, P_{CO_2}, pH, P_{O_2}, and Creat (n = 10) was excellent and less than 4%.

Accuracy and linearity studies were also performed, and all the analytes recovered values were within acceptable ranges as shown in Table 2. The accuracy and linearity of iCa^{2+} were analyzed on EPOC with a maximum deviation of 3.8%. All the results were accurate and linear within the total allowable error (TAE) of 0.1 mmol/L. The accuracy and linearity of glucose were analyzed on EPOC with a maximum deviation mean of 13.6%. All the results were accurate and linear within the TAE of 6 mg/dL or 10%. The accuracy and linearity of Hct were analyzed with a maximum deviation of 3.1%. All the results were accurate and linear within the TAE of 6%. The accuracy and linearity of K^+ showed a maximum deviation of 4.8% with the TAE of 0.5 mmol/L or 7%, whereas the Na^+ showed a maximum deviation of 1.2% within the TAE of 4.0 mmol/L. The accuracy and linearity of lactate were analyzed on EPOC for a measured range of 0.65 to 22.15 mmol/L. All the results were accurate and linear within the TAE of 0.4 mmol/L or 15.0%. The accuracy and linearity of pH showed a maximum deviation of 0.2% within the TAE of 0.04. The accuracy and linearity of P_{O_2} were analyzed on EPOC. All the results were accurate and linear within the TAE of 9 mm Hg or 10%. The P_{CO_2} analysis showed a maximum deviation of 5.4%. All the results were accurate and linear within the TAE of 5 mm Hg or 8%.

They recovered values across the reportable range in compliance with College of American Pathologists and CLIA guidelines. All parameters tested were linear with a maximum deviation within the limits of TAE.

Reader-to-Reader Comparison Study

Eight readers were compared randomly for all the parameters. The random slopes of the comparisons were all within 2% of unity, the slopes were all close to 0, and the correlations for all parameters were higher than 0.99 (data not shown).

Correlation studies were performed on 40 pediatric samples on EPOC, i-STAT, and ABL 835 Radiometer. The correlation coefficients were calculated using linear regression equations.

Method Comparison of EPOC Versus i-STAT

With the exception of Na^+/Ca^{2+}, the correlation was higher than 0.94 for all the analytes when compared on the 2 instruments. The correlation coefficient of Na^+ was r = 0.91; it was still greater than 0.90; however, the correlation coefficient of Ca^{2+} was r = 0.61, but these low values may be attributed to the very narrow range of values tested. The values of Hct and Hb showed a good correlation

TABLE 3. Concordance Studies of i-STAT With EPOC

	i-STAT			EPOC			R Value
Analyte	Mean	SD	% CV	Mean	SD	% CV	(Correlation Coefficient)
pH	7.39	0.06	0.78	7.40	0.05	0.74	98.6
P_{CO_2}, mm Hg	42.74	5.75	13.5	41.50	6.3	15.2	96.8
P_{O_2}, mm Hg	114.7	90.2	78.6	120.1	97.6	81.2	99.9
Na^+, mmol/L	141.5	3.1	2.2	141.3	3.0	2.1	90.9
K^+, mmol/L	3.8	0.68	17.6	3.8	0.64	16.8	99.7
iCa^{2+}, mmol/L	1.15	0.09	7.7	1.15	0.08	7.2	94.3
Glucose, mg/dL	130.4	64.8	49.7	129.0	61.4	47.6	99.8
Hct, %	29.8	6.7	22.5	28.0	6.1	21.8	94.7
cHb, g/dL	10.1	1.8	17.9	9.6	2.0	21.6	85.7

cHb indicates calculated hemoglobin.

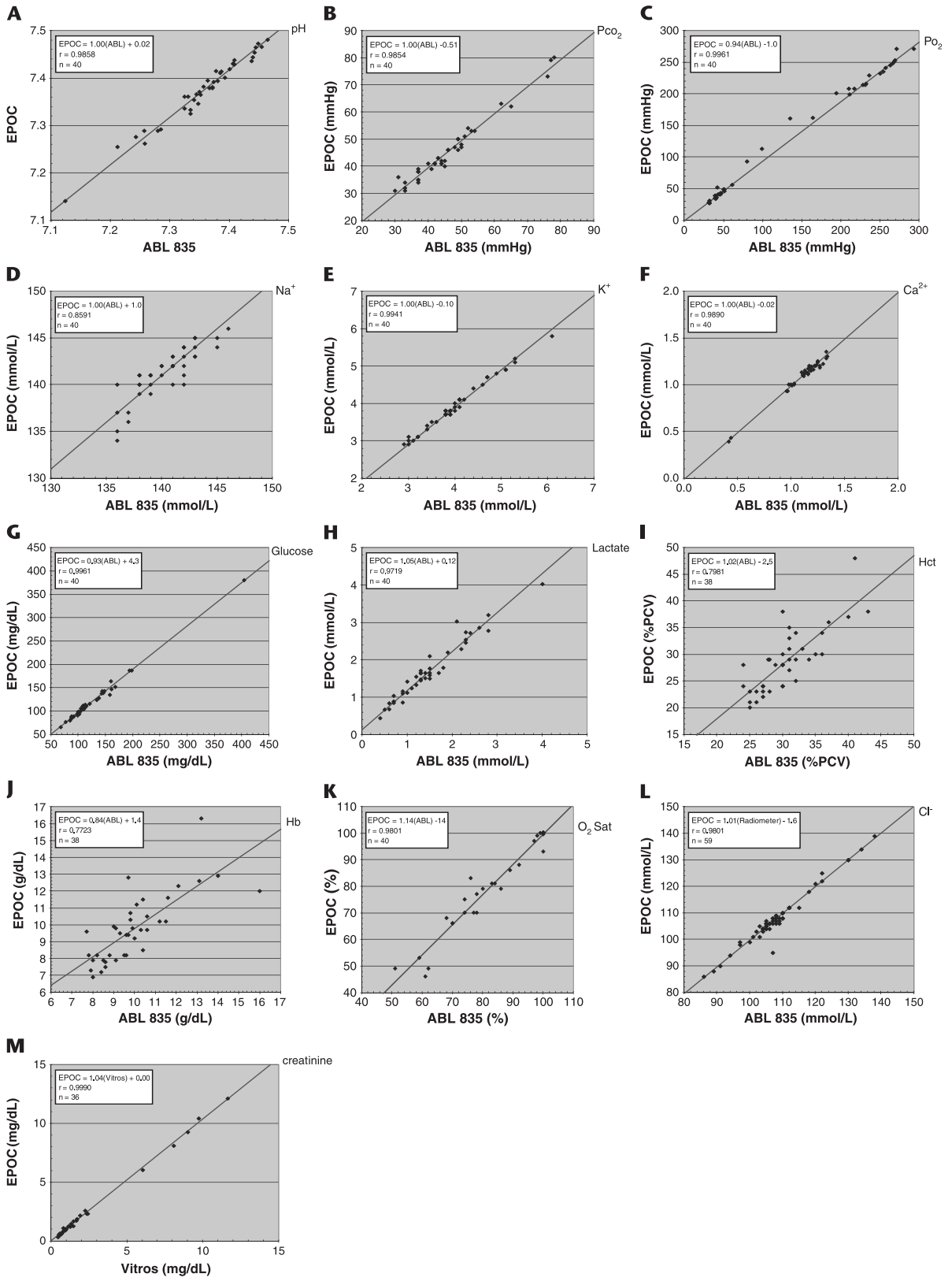

FIGURE 1. As described in the Materials and Methods section, 40 serial samples that were tested on the ABL 835 Radiometer were also simultaneously run on the EPOC and the linear regression graphs were computed, and the regression equation and correlation coefficient (r) are provided in the Figures for pH (A), Pco_2 (B), Po_2 (C), Na^+ (D), K^+ (E), Ca^{2+} (F), glucose (G), lactate (H), Hct (I), Hb (J), O_2 Sat (K), Cl^- (L), and creatinine (M). Only the creatinine comparisons were performed on the EPOC and the Vitros 5600 analyzer.

of r > 0.94, attributing to the fact that EPOC and i-STAT use the same technology for analysis of these analytes. The slopes of the regression analysis were all within +/−10% of unity and the intercepts were all within 10% of the extremes of reportable range with the exception of P_{CO_2} as shown in Table 3. Notably, because of the need to use different test cartridges for lactate, chloride, and creatinine, the comparison of these parameters was not done with the i-STAT.

Method Comparison of EPOC and ABL 835 Radiometer

With the exception of Na^+, Hct, and Hb, the correlation coefficients for the comparison between the 2 methods were r > 0.97. The r value for Na^+ was 0.86, for Hct was r = 0.80, and for Hb was r = 0.77. The discrepant correlation for sodium is attributed to a very narrow range of values tested. This is further corroborated by the fact that the correlation coefficient values for Hct and Hb show more discordance (r > 0.91) (in comparison with i-STAT; r > 0.94) because EPOC and ABL 835 Radiometer use different analytical technologies. The slopes of regression analysis were all within 10% of unity, and the intercepts were all within 10% of extremes of reference ranges with the exception of the same 2 analytes (Figs. 1A–L). Although creatinine is not available on the ABL 835 Radiometer, comparison of creatinine was not done with EPOC; however, comparison of creatinine on EPOC versus the Vitros 5600 showed excellent correlation (Fig. 1M).

DISCUSSION

There is limited data to evaluate the performance of the new EPOC blood gas and electrolyte analyzer in measuring blood gases, electrolytes, and metabolites, particularly in the pediatric hospital setting.

We evaluated the modified EPOC blood gas and electrolyte analyzer, which includes testing of additional analytes including creatinine and chloride and collected data that emphasize the intra-assay and interassay precision and accuracy of the EPOC blood gas and electrolyte analyzer.

The addition of analytes creatinine and chloride is particularly useful to provide a more accurate physiologic picture of both renal and lung function, allowing the ability to evaluate for both respiratory and metabolic acidosis and alkalosis without the need for an additional sample as required by the i-STAT, which also uses additional test cartridges for these measurements.

Although intra-assay and interassay precision studies showed a CV of less than 5% for all analytes evaluated, the accuracy and linearity studies also showed excellent accuracy and linearity of all analytes across the reportable range in compliance with the College of American Pathologists and CLIA guidelines.

In addition, the methods comparison results show high level of correlation between the i-STAT POC device and also the criterion standard ABL 835 Radiometer.

The only other evaluation of the EPOC system reported was by Stotler and Kratz[7] at their tertiary academic center. However, an analysis of the modified EPOC system, which includes both Cl^- and creatinine analytes, was not made at their tertiary academic center. Moreover, our evaluation reflects results exclusive to a pediatric center and carries a special emphasis on the cost-benefit analysis of the EPOC system when compared with the i- STAT system, which was not discussed with respect to their tertiary academic center.

When compared with the i-STAT method, the EPOC blood gas and electrolyte analyzer has many additional advantages. The EPOC system uses a single test card with all the different analytes including glucose, lactate, creatinine, and chloride, whereas the i-STAT system uses multiple test cartridges for the same results. Whereas the i-STAT system reports results in less than 2 minutes, the EPOC blood gas and electrolyte analyzer has results ready in less than 30 seconds, significantly decreasing TAT in the emergency setting. Test cards for EPOC may be stored for up to 6 months at room temperature unlike the i-STAT system. Each reagent for the EPOC has direct bar coding, ensuring easy traceability. The EPOC system has wireless connectivity (Wi-Fi and bluetooth), and transmission of data from bedside to laboratory information systems is instant and automatic. The touch screen interface of the EPOC system is easy to use. The EPOC system uses calibration before sample application to minimize the chances of error and possible redraw of patient.

Lastly, the smart card technology of EPOC reduces cost and maximizes efficiency in the hospital setting. The cost of the EPOC analyzer is less than the i-STAT analyzer ($5991 vs $9065). Despite the additional interface cost of the EPOC analyzer, the total supply cost per annum at our pediatric hospital is less for the EPOC analyzer as compared with the i-STAT analyzer ($5228 vs $7274).

With expansion of health care to remote facilities and need for immediate laboratory results in the critical care setting, we conclude that the operational advantages, interface capabilities, and cost-benefit ratio of the EPOC blood gas and electrolyte analyzer will propel it as a favorable bedside POC instrument particularly in the intensive care setting of both adult and pediatric hospitals.

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