Journal of Veterinary Science

JVS

Original Article
Clinical Pathology

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Comparison of the bovine blood gas parameters produced with three types of portable blood gas analyzers

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ABSTRACT

Background: A definite diagnosis should be made in the bovine practice field, however, it was difficult to perform laboratory analysis immediately. Currently, three types of portable blood gas analyzers are available in Korea.

Objectives: This study aimed to evaluate the correlations among these three analyzers.

Methods: Seventy-two plasma samples from Holstein-Friesian cows were used for blood gas analysis, and three instruments (EDAN i15 Vet, VETSCAN i-STAT, and EPOC) were operated simultaneously. Moreover, plasma calcium levels were compared between these portable analyzers and blood chemistry device, which is usually used in a laboratory environment. Pearson analysis was performed to confirm the correlation of each parameter produced with the three instruments and blood chemistry analyzer.

Results: As results, high correlation was observed in parameters of pH, pO_2, potassium ion, ionized calcium, and glucose ($p < 0.001$, $r > 0.7$). In addition, pCO_2 showed a moderate correlation among the three analyzers ($p < 0.001$, $r > 0.5$), and there was no correlation among all instruments for sodium ions. There was also a high correlation between ionized calcium from the three portable devices and total calcium from the biochemistry analyzer ($p < 0.001$, $r > 0.9$).

Conclusions: In conclusion, there was a high correlation between results from the three different blood gas analyzers used in the bovine clinical field in Korea. Thus, a consistent diagnosis can be made even with different equipment if the operator is aware of the strengths and weaknesses of each piece of equipment and operates it properly.

Keywords: Blood gas analysis; calcium; cattle; pH; point-of-care systems

INTRODUCTION

In bovine practice as in other animals, blood analysis can be used to diagnose several diseases or systemic conditions [1-4]. In peripartal dairy cows, hypocalcemia or hypophosphatemia after parturition can be diagnosed by measuring mineral levels such as calcium (Ca) in the blood [5,6]. Blood mineral balance is important in dairy cows, as blood Ca, phosphate, and magnesium levels can affect recovery and immunity during the postpartum period [1,2,5-7]. In addition, in calves suffering from diseases such as diarrhea, imbalances of electrolytes

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Conflict of Interest
The authors declare no conflicts of interest.

and energy metabolites may be observed in blood analyses [8-11]. Diarrheas can cause loss of electrolytes and water from body fluids, which can lead to decreased milk intake and ataxia due to dehydration, metabolic acidosis, and decreased energy [8-11]. Therefore, an accurate diagnosis of the individual's condition and supplementation of electrolytes, minerals, and energy sources are not performed at the proper time, which may result in death [2,7-11].

For animals for which it is difficult to obtain an accurate history, a definitive diagnosis of the systemic state is essential for a successful treatment [8-10,12]. In particular, it is necessary to understand the overall physical condition through physical examination and blood analyses [4,8-10]. Currently, a variety of analytical equipment are being used in veterinary medicine, and rapid diagnosis and analyses of the patient's condition have been performed [2,4,8,10,13,14]. Most of these analytical devices are used in a stable laboratory environment, and the use of portable analyzers in the field is rare than laboratory analysis [12,15]. However, in large animals, especially cattle, unlike companion animals, it is rare to bring patients to the veterinary hospital; therefore, it is necessary to perform a quick and accurate diagnosis in the clinical field [12,14]. Owing to these limits, portable blood gas analyzers have been actively used in the clinical field for cattle. Blood gas analyzers have been produced by various companies for blood gas analysis, and the range or unit of measurement may differ depending on the analyzer [12,13]. In addition, even with the same sample, there may be differences in analysis results depending on the analyzer, which may cause critical errors in the diagnosis [13]. Therefore, it was necessary to compare the results of each analyzers.

The purpose of this study was to compare the test results produced by three types of portable blood gas analyzers currently available in the bovine clinical field in Korea. In addition, plasma Ca levels were compared between these portable analyzers and blood chemistry device, which is usually used in a laboratory environment.

MATERIALS AND METHODS

This experiment was conducted after approval by the Institutional Animal Care Use Committee of Seoul National University (SNU-181105-3). In this study, 72 plasma samples from dairy cows from one farm were used for the analyses. Blood sampling was conducted in the jugular vein, and blood was dispensed into heparin tubes immediately after collection. Within 1 h after sampling, the plasma was separated by centrifugation at 2,000 × g for 15 min at room temperature and stored in a deep freezer at −70℃ until the analysis. Three types of portable blood gas analyzers were used; EDAN i15 Vet (EDAN, Shenzhen, China), VETSCAN i-STAT (Abbott, USA) with a CG8+ cartridge, and EPOC blood gas analysis system (Epocal, Canada). All the three instruments were operated simultaneously at room temperature by a trained veterinarian. Among the results of each analyzer, correlation coefficients were determined only for measured parameters, such as pH, pCO_2, pO_2, potassium ions (K^+), ionized calcium (iCa^{2+}), sodium ions (Na^+), and glucose. As three devices use the same formula for calculated parameters, such as base excess and bicarbonate, those data were not compared. The formula for bicarbonate and base excess is ($\log HCO_3^- = pH + \log pCO_2 − 7.608$) and ($Base\ excess = HCO_3^- − 24.8 + 16.2 × [pH − 7.4]$), respectively. When the units of ions measured by each analyzer were different, the unit was converted to mM/l and compared. To compare with the iCa^{2+} of portable blood gas analyzers, total calcium (tCa) was analyzed using BS-400 (Mindray, China) as laboratory biochemistry equipment, and the correlation between tCa and iCa^{2+} was confirmed. Statistical analyses were performed using

Table 1. Results of the Pearson correlation analysis of parameters in blood analyses with three different portable blood gas analyzers

Blood analyses	Parameter						
	pH	pO_2	pCO_2	Na^+	K^+	iCa^{2+}	Glucose
Comparison with EDAN and i-STAT							
p value	< 0.001[*]	< 0.001[*]	< 0.001[*]	0.233	< 0.001[*]	< 0.001[*]	< 0.001[*]
r value	0.884[a]	0.746[b]	0.655[b]	−0.142	0.897[a]	0.968[a]	0.798[b]
Comparison with i-STAT and EPOC							
p value	< 0.001[*]	< 0.001[*]	< 0.001[*]	0.228	< 0.001[*]	< 0.001[*]	< 0.001[*]
r value	0.836[a]	0.716[b]	0.593[c]	0.144	0.905[a]	0.973[a]	0.911[a]
Comparison with EDAN and EPOC							
p value	< 0.001[*]	< 0.001[*]	< 0.001[*]	< 0.05	< 0.001[*]	< 0.001[*]	< 0.001[*]
r value	0.784[b]	0.721[b]	0.552[c]	0.238	0.944[a]	0.976[a]	0.837[a]

The correlation was expressed with r value and p value.
pCO_2, partial pressure of carbon dioxide; pO_2, partial pressure of oxygen; Na^+, sodium ion; K^+, potassium ion; iCa^{2+}, ionized calcium.
A significant positive correlation was represented with [a]$0.08 < r$; [b]$0.06 < r < 0.08$; [c]$0.05 < r < 0.06$; and [*]$p < 0.001$.

SigmaPlot 14 (Systat Software Inc., USA). The Pearson method was used for the correlation analyses among the parameters.

RESULTS

Correlation analyses confirmed a significant correlation for all parameters among the three analyzers (**Table 1**). Significant positive correlations were confirmed for pH, K^+, and iCa^{2+} ($r = 0.884$, $r = 0.897$, and $r = 0.968$, respectively) between i-STAT and EDAN. For these two analyzers, a positive correlation was observed between pO_2, pCO_2, and glucose ($r = 0.746$, $r = 0.655$, and $r = 0.798$, respectively). Between i-STAT and EPOC, a strong positive correlation was confirmed in pH, K^+, iCa^{2+}, and glucose ($r = 0.836$, $r = 0.905$, $r = 0.973$, and $r = 0.911$, respectively), also a tendency of positive correlation was shown in pO_2 and pCO_2 ($r = 0.716$ and $r = 0.593$). Between EDAN and EPOC, a strong positive correlation was observed for K^+, iCa^{2+}, and glucose ($r = 0.944$, $r = 0.976$, and $r = 0.837$, respectively), and a significant positive correlation was found in pH and pO_2, ($r = 0.784$ and $r = 0.721$, respectively), although a tendency of positive correlation was found in pCO_2 ($r = 0.552$). However, for Na^+, there was no correlation among the three analyzers.

When the Ca results of the three portable blood gas analyzers and the laboratory chemistry equipment were compared, all blood gas analyzers showed a strong positive correlation with the laboratory analyzer ($r = 0.937$ for EDAN, $r = 0.930$ for EPOC, and $r = 0.927$ for i-STAT; **Table 2**).

Table 2. The results of the Pearson correlation analysis of calcium of blood chemistry analysis with MINDRAY and ionized calcium with the three blood gas analyzers including EDAN, i-STAT, and EPOC

Device	EDAN	i-STAT	EPOC
MINDRAY			
r value	0.937[a]	0.917[a]	0.930[a]
p value	< 0.001[*]	< 0.001[*]	< 0.001[*]
EDAN			
r value		0.968[a]	0.976[a]
p value		< 0.001[*]	< 0.001[*]
i-STAT			
r value			0.973[a]
p value			< 0.001[*]

The correlation was expressed with r value and p value.
Significant positive correlations were represented with [a]$0.08 < r$ and [*]$p < 0.001$.

DISCUSSION

In this study, the results of the three devices currently used, mainly in clinical field environment, were compared. In general, blood gas analysis is mainly performed using whole blood, especially arterial blood, and the most accurate gas analysis results can be obtained [10,16]. However, in the farm animals such as cattle, restraint for collecting arterial blood can be inconvenient, and since previous studies have confirmed that the results of venous blood reflect those of arterial blood, we collected the blood samples from the jugular vein [10,11,17]. In addition, in actual clinical practice, whole blood without anticoagulant is used for blood gas analysis, but in order to compare the three devices under the same conditions we used the plasma samples. This is for the exclusion of blood clotting and hemolysis which may occur until the test proceeds. To prevent the prospect of any errors during the analysis process on the analysis and to eliminate differences depending on the environment, the plasma sample was simultaneously loaded to compare the three analyzers [18].

The main purpose of this experiment was to confirm the correlation between the parameters of each analyzer. The correlation of the results between whole blood and plasma was confirmed in previous analyses, the plasma pH was approximately 0.2 higher than that of whole blood, and there were no significant differences in electrolytes and glucose between plasma and whole blood [17]. As a result of this experiment, the blood pH and pO_2 showed a high correlation between the three analyzers ($p < 0.001$, $r > 0.7$), and pCO_2 also showed a correlation coefficient greater than 0.5. Thus, it can be estimated that even if three devices are used for blood gas analysis, it may not cause a major error in the diagnosis of the acid-base balance. In electrolyte analyses, K^+ showed a high correlation between the three analyzers ($p < 0.001$, $r > 0.8$), but there was no correlation in Na^+. However, the effect of this result on the diagnosis seems negligible, because the value of Na^+ in all the devices was within the normal range.

The number of cartridges used for 72 samples in this study were 78, 72, and 76 in EDAN, i-STAT, and EPOC, respectively. The cartridge failure rates of the three blood gas analyzers were high in the order of EDAN, EPOC, and i-STAT (7.69%, 5.26%, and 0.00%, respectively). This difference in failure rate appears under the same analysis conditions, which is presumed to be due to the difference in the amount of sample required and the method of sample loading into the cartridge. While i-STAT and EPOC required a sample volume of approximately 95 μL, the sample volume for EDAN was 140 μL. Unlike the two devices in which an operator dispenses a sample into the cartridge, the operator inserts a syringe containing the sample into the cartridge, and the device automatically loads the sample in the analysis of the EDAN. It is estimated that fine air in the syringe may be mixed during this process, resulting in a high cartridge failure rate. In this study, a 1-mL syringe was used for sample injection because of the limitation of the sample amount. In the use of the 1-mL syringe, a difference can occur between the speed of sample loading and the speed of syringe plunger pulling, which results in more air in the syringe. In fact, when a 3-mL syringe was used, cartridge failure rarely occurred. Therefore, to prevent cartridge failure, it is necessary to consider the type of syringe used for sampling in EDAN analysis. In addition, the sample in the syringe was injected and covered by the cap of the cartridge in i-STAT, whereas the sample was injected with a syringe and analyzed without the cover in EPOC. It is estimated that exposure to air during the analysis also affects the cartridge failure rate. Although it was operated at room temperature in this study, it is empirically known that low and high temperatures affect the failure rate. The proper operating temperature of the three devices is 10°C–31°C for EDAN, 16°C–30°C for i-STAT, and 15°C–30°C

for EPOC. EDAN has the widest operating temperature range; however, the influence of the operating temperature was not tested in this study.

Three devices have slightly different in general characteristics, such as weight and temperature for storage. The cartridge of EPOC can be stored at room temperature, but i-STAT and EDAN have a disadvantage in that the cartridge should be stored in a refrigerator and brought out at room temperature before analysis. In addition, EPOC had the most parameters that could be tested with one type of cartridge, while EDAN had the fewest. There are eight types of cartridges for i-STAT, and it can be cumbersome to select and analyze a cartridge depending on the inspection target or parameter. Considering that all three analyzers are portable, the weight is also an important factor among the equipment specifications. The analyzer weight was the lightest for i-STAT at approximately 650 g, followed by EPOC at approximately 750 g, and EDAN at 3,650 g for the heaviest. It is estimated that EDAN is the heaviest because the analytic part and printer are integrated, unlike the other two analyzers. Therefore, veterinarians need to decide which analyzer is most suitable for use in the field condition, considering the various advantages and disadvantages of each analyzer.

Recently, a comparison of Ca measurements using the analyzer in the field and laboratory analysis equipment has been performed in several studies [2,4,14,15]. It is presumed that many studies on Ca have been conducted mainly because the level of blood Ca in cattle has an enormous influence on various diseases, conditions, productivity, and disease prognosis [2,6,15]. Therefore, in this study, a comparison among the three portable blood gas analyzers was performed, as well as between the on-site blood gas analyzer and laboratory blood chemistry equipment for blood Ca level measurement. In general, for the diagnosis of hypocalcemia, blood Ca concentration measured with laboratory chemistry equipment is used as a standard. Accordingly, 10 plasma samples diagnosed as hypocalcemia with laboratory analyzer (tCa level in blood ≤ 1.9 mM/L) were included in this experiment, to measure various levels of Ca [7]. These 10 samples showed diagnostic levels of hypocalcemia in three blood gas analyzers (iCa^{2+} level in blood ≤ 0.9 mM/L), and through this, we confirmed that the blood gas analyzers can be used as a diagnosis for Ca disorder. Compared to the laboratory analysis equipment, there was a high correlation with the point-of-care devices in the order of EDAN, EPOC, and i-STAT ($p < 0.001$, $r = 0.937$, $r = 0.93$, and $r = 0.927$, respectively). A high correlation was also observed among the three point-of-care devices ($p < 0.001$, $r > 0.8$). Although the laboratory analysis equipment measured tCa and the field analysis devices measured iCa^{2+}, it is presumed to show a high correlation because generally 50%–55% of tCa in the blood exists in the form of iCa^{2+} [3,15,16].

In conclusion, the three blood gas analyzers showed a significantly high correlation with most measured parameters. Based on these results, it can be concluded that a consistent diagnosis can be made even with different equipment when the operator is aware of the strengths and weaknesses of each piece of equipment and operates it properly.

REFERENCES

1. Chamberlin WG, Middleton JR, Spain JN, Johnson GC, Ellersieck MR, Pithua P. Subclinical hypocalcemia, plasma biochemical parameters, lipid metabolism, postpartum disease, and fertility in postparturient dairy cows. J Dairy Sci. 2013;96(11):7001-7013.
   PUBMED | CROSSREF

2. Leno BM, Martens EM, Felippe MJB, Zanzalari KP, Lawrence JC, Overton TR. Short communication: relationship between methods for measurement of serum electrolytes and the relationship between ionized and total calcium and neutrophil oxidative burst activity in early postpartum dairy cows. J Dairy Sci. 2017;100(11):9285-9293.
PUBMED | CROSSREF

3. Martinez N, Sinedino LD, Bisinotto RS, Ribeiro ES, Gomes GC, Lima FS, et al. Effect of induced subclinical hypocalcemia on physiological responses and neutrophil function in dairy cows. J Dairy Sci. 2014;97(2):874-887.
PUBMED | CROSSREF

4. Yilmaz O, Karapinar T. Evaluation of the i-STAT analyzer for determination of ionized calcium concentrations in bovine blood. Vet Clin Pathol. 2019;48(1):31-35.
PUBMED | CROSSREF

5. Kronqvist C, Emanuelson U, Spörndly R, Holtenius K. Effects of prepartum dietary calcium level on calcium and magnesium metabolism in periparturient dairy cows. J Dairy Sci. 2011;94(3):1365-1373.
PUBMED | CROSSREF

6. Reinhardt TA, Lippolis JD, McCluskey BJ, Goff JP, Horst RL. Prevalence of subclinical hypocalcemia in dairy herds. Vet J. 2011;188(1):122-124.
PUBMED | CROSSREF

7. Goff JP. The monitoring, prevention, and treatment of milk fever and subclinical hypocalcemia in dairy cows. Vet J. 2008;176(1):50-57.
PUBMED | CROSSREF

8. Dillane P, Krump L, Kennedy E, Sayers RG, Sayers GP. Determining the predictive capability of a Clinical Assessment Scoring Chart to differentiate severity of the clinical consequences of neonatal calf diarrhea relative to gold-standard blood gas analysis. PLoS One. 2020;15(4):e0230708.
PUBMED | CROSSREF

9. Lee SH, Choi EW, Kim D. Relationship between the values of blood parameters and physical status in Korean native calves with diarrhea. J Vet Sci. 2020;21(2):e17.
PUBMED | CROSSREF

10. Lee S, Ok S, Kwon H, Kim D. Arterial and venous blood gas, electrolytes, biochemical and hematological values in healthy Korean native calves. J Vet Clin. 2015;32(6):499-503.
CROSSREF

11. Sayers RG, Kennedy A, Krump L, Sayers GP, Kennedy E. An observational study using blood gas analysis to assess neonatal calf diarrhea and subsequent recovery with a European Commission-compliant oral electrolyte solution. J Dairy Sci. 2016;99(6):4647-4655.
PUBMED | CROSSREF

12. Karapinar T, Kaynar O, Hayirli A, Kom M. Evaluation of 4 point-of-care units for the determination of blood l-lactate concentration in cattle. J Vet Intern Med. 2013;27(6):1596-1603.
PUBMED | CROSSREF

13. Kirsch K, Detilleux J, Serteyn D, Sandersen C. Comparison of two portable clinical analyzers to one stationary analyzer for the determination of blood gas partial pressures and blood electrolyte concentrations in horses. PLoS One. 2019;14(2):e0211104.
PUBMED | CROSSREF

14. Suzuki K, Kondo N, Takagi K, Nishikawa A, Murakami Y, Otsuka M, et al. Validation of the bovine blood calcium checker as a rapid and simple measuring tool for the ionized calcium concentration in cattle. J Vet Med Sci. 2021;83(5):767-774.
PUBMED | CROSSREF

15. Neves RC, Stokol T, Bach KD, McArt JAA. Method comparison and validation of a prototype device for measurement of ionized calcium concentrations cow-side against a point-of-care instrument and a benchtop blood-gas analyzer reference method. J Dairy Sci. 2018;101(2):1334-1343.
PUBMED | CROSSREF

16. Lam V, Dhaliwal SS, Mamo JC. Adjustment of ionized calcium concentration for serum pH is not a valid marker of calcium homeostasis: implications for identifying individuals at risk of calcium metabolic disorders. Ann Clin Biochem. 2013;50(Pt 3):224-229.
PUBMED | CROSSREF

17. Ro Y, Choi W, Park J, Choe E, Kim D. Changes in plasma pH and blood and urinary macromineral concentrations in experimentally induced hypocalcemic cows with Na_2EDTA. J Vet Med Sci. 2020;82(7):962-966.
PUBMED | CROSSREF

18. Gokce G, Citil M, Gunes V, Atalan G. Effect of time delay and storage temperature on blood gas and acid-base values of bovine venous blood. Res Vet Sci. 2004;76(2):121-127.
PUBMED | CROSSREF