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Short communications

Comparison of bicarbonate and base excess values analyzed by four different blood gas analyzers

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Abstract
Comparison of the calculation formula, reproducibility, correlation and variation of bicarbonate ion concentration (HCO_3^-), and base excess value (BE) among four blood-gas analyzers was performed. No HCO_3^- and BE values calculated from the formulas showed any clinically significant difference, and all analyzers showed good correlation on their measurements. On the actual measurement of a specific sample, however, BE values from the same sample ranged between –6.3 and –15.7, which might affect therapeutic strategy. Caution should be taken for the assessment of data if different types of blood-gas analysis devices are used in the same facility.

Key words Blood gas analysis · Base excess · Bicarbonate

A wide variety of blood-gas analyzers, such as portable and multi-channel analyzers have become available and have been utilized recently. It is well known that blood-gas analysis can easily produce errors in a series of measurements. Bicarbonate ion concentration (HCO_3^-) and base excess (BE) value are important factors for the understanding of acid-base balance that are calculated from the pH, partial pressure of carbon dioxide (P_{CO_2}), and hemoglobin concentration (Hb). But HCO_3^- and BE can be influenced by various factors; e.g., differences among calculation formulas (some analyzers do not use Hb), and the accuracy of pH, P_{CO_2}, and Hb. This study was carried out to compare the effects of these factors on HCO_3^- and BE among the following four blood-gas analyzers: (1) ABL-520 (Radiometer, Copenhagen, Denmark; ABL); (2) i-STAT Portable analyzer 200 (i-STAT, East Windsor, NJ, USA; i-STAT); (3) STAT PROFILE-M (Nova Biomedical, Waltham, MA, USA; SP-M); and (4) Rapidlab-860 (Bayer, Leverkusen, Germany; R-860). The Ac-T10 (Beckman-Coulter, Fullerton, CA, USA; Act-10), which measures Hb by a cyanmethemoglobin method, was used as the control device for Hb. The ABL and i-STAT analyzers employ manual injection of the sample, while the SP-M and R-860 employ an automated aspiration system. After consent had been obtained, heparinized arterial blood was sampled from patients ($n = 71$) during general anesthesia and analyzed immediately. A correction coefficient was not used on every device. Significance ($P < 0.05$) was tested by means of non-paired *t*-test, and correlation was calculated by the maximum-likelihood method, followed by the χ^2 test. The following units were used: P_{CO_2}, mmHg; HCO_3^-, mmol·l^{-1}; BE, mmol·l^{-1}; and Hb, g·dl^{-1}.

HCO_3^- and BE were calculated with a personal computer, under the following conditions: (1) P_{CO_2}, 40; Hb, 12.0; and pH, variable; (2) pH, 7.40; Hb, 12.0; and P_{CO_2}, variable; (3) pH, 7.40; P_{CO_2}, 40.0; and Hb, variable. Reproducibility was examined by repeating the measurements consecutively five times on each device, and the coefficient of variation (CV) was calculated. After the measurement of blood samples, correlations and differences were calculated for HCO_3^-, BE, and Hb.

Tables 1 to 3 show the results of computer simulations of the HCO_3^- and BE with variable pH, P_{CO_2}, and Hb values. When pH was variable, the maximum difference among the four devices was 1.2 for HCO_3^- and 2.3 for BE. In the same way, when P_{CO_2}, was variable, the maximum difference was 1.2 for HCO_3^- and 2.8 for BE, and when Hb was variable, the maximum difference was 1.392 for BE. Reproducible tests showed over 2% variance on the i-STAT for P_{CO_2}, BE, and Hb and over 2% variance on the SP-M for BE (Table 4). But the variance did not seem to affect the data clinically. In addition, good correlations were shown between the ABL-520 and the other three devices for HCO_3^- (Fig. 1) and BE (Fig. 2).

Because the calculation formulas and the measurement methods were different among the devices, it was

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Table 1. Comparison of calculation formula; P_{CO_2}, 40.0; Hb, 12.0; and variable pH

	HCO_3^- (mmol·l^{-1})						BE (mmol·l^{-1})					
pH	ABL	i-STAT	SP-M	R-860	Range	CV	ABL	i-STAT	SP-M	R-860	Range	CV
7.60	39.5	39.3	39.6	38.4	1.2	1.4	15.7	17.7	17.1	15.4	2.3	6.7
7.50	30.9	31.2	31.5	30.5	1.0	1.4	7.4	7.4	8.3	6.8	1.5	8.7
7.45	27.4	27.8	28.1	27.2	0.9	1.4	3.6	3.6	4.4	3.0	1.4	15.5
7.40	24.3	24.8	25.0	24.2	0.8	1.6	0.1	0.1	0.8	–0.5	1.3	49.9
7.35	21.5	22.1	22.3	21.6	0.8	1.7	–3.3	–3.3	–2.5	–3.7	1.2	17.0
7.30	19.1	19.7	19.9	19.2	0.8	1.9	–6.4	–6.4	–5.5	–6.7	1.3	9.0
7.20	15.0	15.6	15.8	15.3	0.8	2.2	–12.1	–12.1	–11.0	–12.1	1.3	5.2

CV, coefficient of variation

Table 2. Comparison of calculation formula; pH, 7.40; Hb, 12.0; and variable P_{CO_2}

P_{CO_2}	HCO_3^- (mmol·l^{-1})						BE (mmol·l^{-1})					
(mmHg)	ABL	i-STAT	SP-M	R-860	Range	CV	ABL	i-STAT	SP-M	R-860	Range	CV
60	36.4	37.2	37.5	36.3	1.2	1.6	9.9	12.4	11.2	9.6	2.8	11.9
50	30.3	31.0	31.3	30.3	1.0	1.6	5.0	6.2	6.0	4.6	1.6	14.2
45	27.8	27.9	28.1	27.2	0.9	1.3	2.6	3.1	3.4	2.0	1.4	22.1
40	24.3	24.8	25.0	24.2	0.8	1.6	0.1	0.0	0.8	–0.5	1.3	48.7
35	21.2	21.7	21.9	21.2	0.7	1.6	–2.5	–3.1	–1.8	–3.0	1.3	22.9
30	18.2	18.6	18.8	18.2	0.6	1.6	–5.1	–6.2	–4.4	–5.5	1.8	14.2
20	12.1	12.4	12.5	12.1	0.4	1.6	–10.7	–12.4	–9.6	–10.6	2.8	11.5

CV, coefficient of variation

Table 3. Comparison of calculation formula; pH, 7.40; P_{CO_2}, 40.0; and variable Hb

Hb	BE (mmol·l^{-1})					
(g·dl^{-1})	ABL	i-STAT	SP-M	R-860	Range	CV
18	0.059	–0.022	0.753	–0.433	1.320	45.2
16	0.060	–0.022	0.781	–0.449	1.332	46.7
14	0.060	–0.022	0.810	–0.465	1.345	48.3
12	0.060	–0.022	0.838	–0.481	1.357	49.8
10	0.060	–0.022	0.866	–0.498	1.368	51.4
8	0.060	–0.022	0.894	–0.514	1.380	52.9
6	0.060	–0.022	0.922	–0.530	1.392	54.4

CV, coefficient of variation

Table 4. Reproducibility of measurements

Parameter	Device	Mean	SD	CV
pH	ABL	7.307	0.005	0.06
	i-STAT	7.305	0.008	0.10
	SP-M	7.434	0.001	0.02
	R-860	7.143	0.002	0.02
P_{CO_2} (mmHg)	ABL	42.2	0.406	0.96
	i-STAT	42.4	1.081	2.55
	SP-M	39.0	0.527	1.35
	R-860	62.8	0.477	0.76
HCO_3^- (mmol·l^{-1})	ABL	20.5	0.045	0.22
	i-STAT	21.0	0.000	0.00
	SP-M	26.5	0.268	1.02
	R-860	21.0	0.130	0.62
BE (mmol·l^{-1})	ABL	–4.9	0.084	1.70
	i-STAT	–5.2	0.447	8.60
	SP-M	2.7	0.259	9.52
	R-860	–7.8	0.130	1.67
Hb (g·dl^{-1})	Act-10	12.0	0.055	1.10
	ABL	9.3	0.122	1.32
	i-STAT	10.2	1.924	4.30
	SP-M	9.5	0.055	0.82
	R-860	8.4	0.084	1.00

Measurements were repeated five times for each test
CV, coefficient of variation

understandable that the computer simulation resulted in differences. But these differences could be important in regard to the issue of accuracy control. Using the actual Hb value is important for consideration of metabolism [1,2], but the actual Hb measurement itself includes accidental error. Reproducibility tests showed clinically acceptable results for all devices. Correlation tests for pH, P_{CO_2}, P_{O_2}, BE, and Hb showed good relationships between the ABL-520 and the other four devices, but differences in data were seen in the i-STAT and SP-M for all factors, and in the R-860 for BE when compared with the ABL-520. It is supposed that these differences resulted from differences in the range, properties, and accuracy of the pH and P_{CO_2} electrodes, together with the differences in the calculation formulas. For blood-gas analysis, there are guidelines, such as the accuracy proof program, and many facilities employ them [3,4].

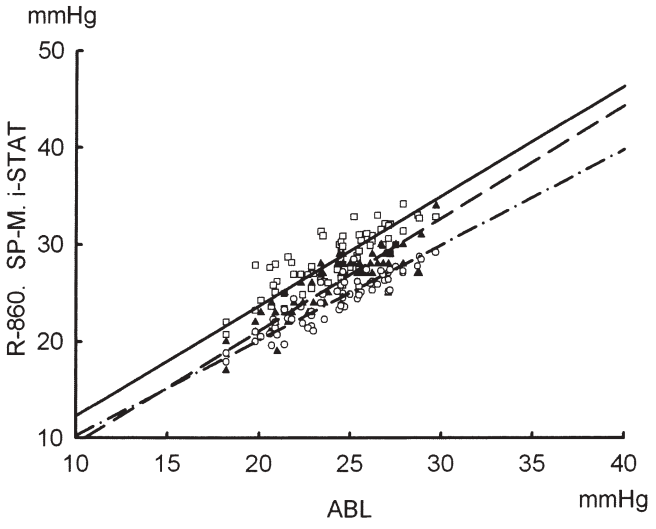

Fig. 1. Correlation between ABL-520 (Radiometer; *ABL*) and STAT PROFILE-M (Nova Biomedical; *SP-M*) (y = 1.136x + 0.964, $r = 0.824$, $n = 69$, *solid line and open squares*), i-STAT portable analyzer 200 (i-STAT Corporation; *i-STAT*) (y = 1.165x – 2.203, $r = 0.875$, $n = 69$, *dashed line* and *closed triangles*), and Rapidlab-860 (Bayer; *R-860*) (y = 0.987x + 0.385, $r = 0.908$, $n = 68$, *dotted dashed line and open circles*) for HCO_3^-

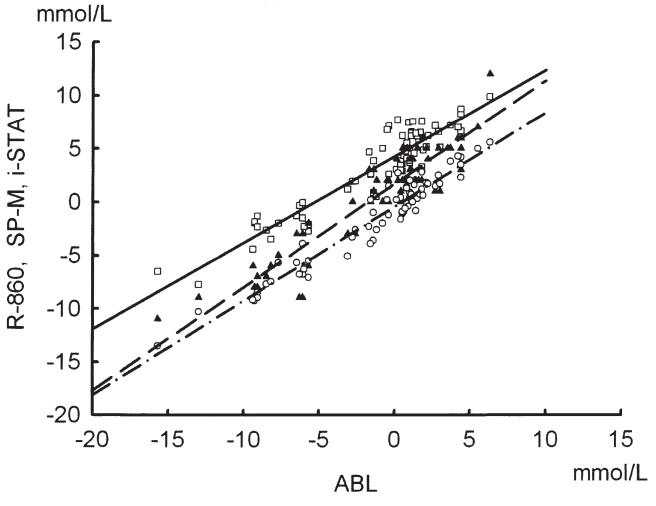

Fig. 2. Correlation between ABL and SP-M (y = 0.810x + 4.279, $r = 0.934$, $n = 68$, *solid line and open squares*), i-STAT (y = 0.968x + 1.695, $r = 0.932$, $n = 67$, *dashed line and closed triangles*), and R-860 (y = 0.883x + 0.439, $r = 0.968$, $n = 68$, *dotted dashed line and open circles*) for base excess (BE)

It is thought that the quality of electrodes plays a major role in the accuracy of blood-gas analysis. Possible factors causing accidental error can be divided into pre-analysis factors and those involved during analysis. Possible pre-analysis factors are the effects of drugs such as halothane [5], and the injection method used at the sampling port; further study will be required to examine these. Factors involved during analysis include problems arising from contamination, the temperature of the sample, and the condition of the electrodes. Shifts in the of values of pH and P_{CO_2} per 1°C temperature change are reported to be 0.0147 and 4.3%, respectively [1]. Because all the devices we used were well maintained and the inside temperature was kept at 37 ± 0.1°C, it seemed that the most likely reason causing the differences in data among the devices may have been the quality of the electrode. HCO_3^- and BE are very important as clinical data, because the acid-base balance is evaluated by them [6]. In combination with pH and P_{CO_2}, these parameters indicate whether an abnormality is due to respiratory or metabolic malfunction, and whether it is primary or secondary. The differences in calculation formulas between the devices may be negligible clinically, but the difference in actually indicated values can influence the therapeutic strategy. For example, this study resulted in a maximum difference of BE between the ABL-520 (–15.7) and the SP-M (–6.3) from the same sample, which could affect the decision on courses of treatment.

In this study, computer simulation showed clinically negligible differences in HCO_3^- and BE among the devices. But actual blood-gas analysis testing resulted in broader differences among the devices. It is suggested that frequent calibration and accuracy control are very important when different types of blood-gas analysis devices are used in the same facility.

Appendix

Calculating formulas for each device

ABL-520 [7–9]

$$HCO_3^- = 0.230 * P_{CO_2} * \text{antilg}(pH - pk_p)$$
$$pk_p = 6.125 - \lg(1 + \text{antilg}(pH - 8.7))$$
$$BE = 0.5 * (8 * a' - 0.919)/a' + 0.5 * [((0.919 - 8 * a')/a')^2 - 4*(24.47 - HCO_3^-(5.33))/a']^{1/2}$$
$$a' = 0.00404 + 0.000425 * tHb$$
$$HCO_3^-(5.33) = 0.230 * 5.33 * \text{antilg}((pH(st) - 6.161)/0.9524)$$
$$pH(st) = pH + \lg(5.33/P_{CO_2}) * (pH(Hb) - pH)/(\lg(P_{CO_2}(Hb)) - \lg(7.5006 * P_{CO_2}))$$
$$pH(Hb) = 0.0406 * tHb + 5.980 - 1.920 * \text{antilg}(-0.16169 * tHb)$$
$$\lg(P_{CO_2}(Hb)) = -0.017674 * tHb + 3.4046 + 2.12 * \text{antilg}(-0.15158 * tHb)$$
$$tHb(\text{mmol/l}) = cRHb + cO_2Hb + cCOHb + cMetHb$$

i-STAT [10]

$$\log_{10}[HCO_3^-] = pH + \log(P_{CO_2}) - 7.608$$
$$BE = [HCO_3^-] - 24.8 + 16.2(pH - 7.40)$$

SP-M [11]

$$\log_{10}[HCO_3^-] = pH + \log_{10}(P_{CO_2}) - 7.604$$

$$BE = (1 - 0.014[Hb])[HCO_3^-] - 24 + (1.43[Hb] + 7.7)(pH - 7.4)$$

$$Hb = Ht/3.0(g/dl)$$

R-860 [12,13]

$$HCO_3^- = 0.0307 * (P_{CO_2}) * 10^{(pH-6.105)}$$

$$BE = (1 - 0.014 * tHb)[(HCO_3^- - 24.8) + (1.43 * tHb + 7.7)(pH - 7.40)]$$

$$tHb(g/dl) = FHHb + cO_2Hb + cCOHb + cMetHb.$$

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