The Bioelectronic Factors of Human Body Fluids and Intravenous Replacement Solutions

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In this paper the analytical method of the pH, rH_2 and specific resistance of body fluids with B.E.-VINCENT Unit was described. From the values of the pH, rH_2 and specific resistance, other three bioelectronic factors, the redox potential, milliampere and microwatts, were calculated. With this technique the bioelectronic factors of arterial and venous blood and urine obtained from 20 young healthy adults were examined. Those of arterial and venous blood showed almost identical values. The urinary values of the pH, milliampere and microwatts varied as compared to those of blood. The bioelectronic factors of the various intravenous replacement solutions and blood components were considerably different from those of blood. It is considered that the bioelectronic factors of patient's blood should be checked repeatedly and maintained in an appropriate state when massive fluid therapy is required. (Key words: bioelectronic factors, redox potential, body fluids, intravenous replacement solutions)

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The pH of body fluids is recognized to be an important environment factor exercising a decisive influence on the vital activities of living organisms. Therefore, the pH of body fluids has been extensively examined in clinical subjects. The pH value is calculated through the logarithms of the reversed value of the hydrogen ion concentration, such as

$$pH = -\log(H^+) = \log\frac{1}{H^+}$$ [1, 2]

From the physico-chemical principles, the following oxidation-reduction equation is introduced.

$$H_2 = 2H^+ + 2e^- \quad (1)$$

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With the classical formula of Nernst, based on the second law of thermodynamics, the next equation is induced.

$$E = \frac{RT}{2F}\log\frac{2H^+}{H_2}$$ [1, 3] (2)

Where E represents the measured potential in proportion to the H_2 electrode as reference potential, R the molar gas constant, equal to 8.315 joules per degree, T the absolute temperature, F the faraday constant, equal to 96,500 coulombs, respectively.[2]

The equation (2) can be written as follows;

$$E = \frac{RT}{2F}\left(\log\frac{1}{H_2} - 2\log\frac{1}{H^+}\right) \quad (3)$$

$$\log\frac{1}{H_2} = rH_2,\ \log\frac{1}{H^+} = pH$$

Therefore,

$$E = 0.03\,(rH_2 - 2pH) \quad (4)$$

$$rH_2 = 33.33E + 2pH \quad (5)$$

From the redox potential (E) and specific resistance (R) it was possible to calculate I

(milliampere) and μW by using the following formulae;[1]

$E/R = I$ (milliampere)

$E \cdot I = E^2/R = \mu W$ (microwatts)

As the pH, rH_2 and redox potential (E) are inseparably linked, it is impossible to look upon one of them apart from the others as often happens for pH measurements. Recently, it has become possible to measure the bioelectronic factors such as pH, rH_2 and redox potential of body fluids with B.E.-VINCENT apparatus from Med-Tronik Co. FRG. We have measured the bioelectronic factors in addition to many other biochemical factors in both human blood and urine. This paper is the preliminary report concerning the bioelectronic factors of human body fluids and various intravenous replacement solutions.

Methods

1) Instruments

The B.E.-VINCENT apparatus with a combined electrode was used for the measurement of pH, rH_2 and specific resistance of blood and urine (fig. 1).

Calibration;

For the pH electrode, calibration was made by two standard solutions with pH values 4.00 and 7.00.

For calibration of the rH_2 electrode, the rH_2 value was adjusted to 23.2 when pH 7.00 standard solution was introduced into the sample chamber, and to 17.2 when pH 4.00 standard solution was used (fig. 2)[1].

The final adjustment of the rH_2 electrode was done with 0.15 mol phosphate buffer solution (pH 7.00) dissolved in a small amount of quinhydrone crystal immediately before the calibration. Quinhydrone solution has been proved to have the activity of hydrogen ion as shown by the equation[4].

$E = 0.699 - 0.0592pH$ (volts) ($25^\circ C$)

The rH_2 value was calculated from the equation[5].

The calibration of the specific resistance electrode was done with N/10 and N/50 KCl solution. The correction factors for various KCl solutions are illustrated in table 1.

2) Subjects

We measured the bioelectronic factors of arterial and venous blood and urine obtained from adult healthy volunteers (23--29 years old, n=20) before per os intake in the morning. Besides measuring bioelectronic factors, a chemical anaylsis of blood was done as follows; arterial blood gases with Acid-base Laboratory ABL-2, serum and urinary electrolyte concentrations with electrolyte analyzer NOVA 10 and NOVA 2, blood lactate concentrations with OMRON lactate analyzer, blood glucose concentrations with Dextrometer and hematocrit by centrifugation of the blood in a capillary

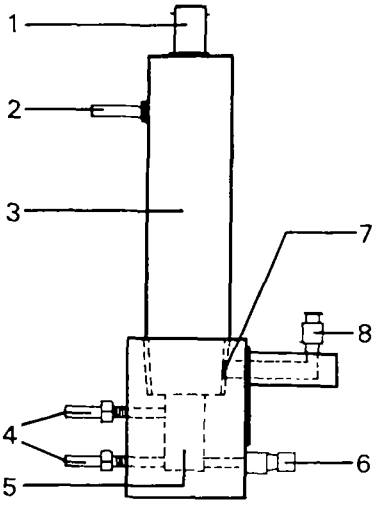

Fig. 1. The VINCENT Combo-Electrode
1. BNC-connector system for pH measurement
2. Banana plug connection for rH_2 measurement
3. Electrode housing incorporating the pH measurement electrode, reference electrode and rH_2 electrode
4. Measurement pins for resistance measurement
5. Measurement chamber for holding the measurement fluid
6. Take-up tube for injection needle in blood collection; Outlet opening for measurement fluids
7. Inlet opening into inside of electrode housing
8. Take-up tube with connection piece for attaching the syringe

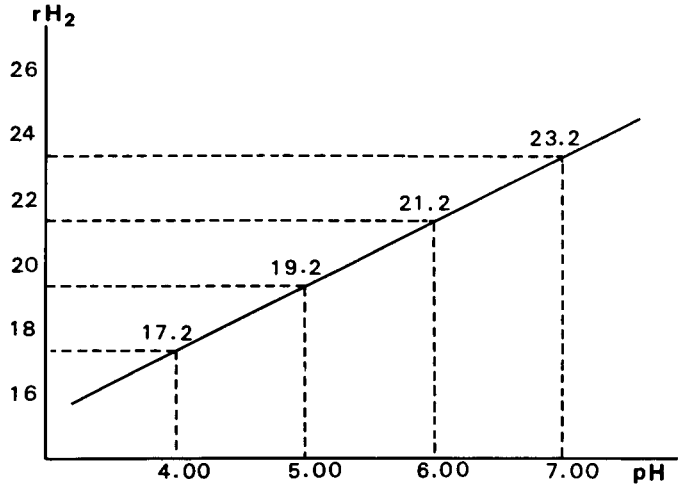

Fig. 2. Relationship between pH and rH_2

Table 1. The correction factors for various KCl solutions

Temperature	KCl concentration		
	N/10	N/50	N/100
15°	95.3 ohm	446 ohm	872 ohm
16°	93.3	436	852
17°	91.3	426	834
18°	89.4	417	817
19°	87.5	408	800
20°	85.7	400	782
21°	84.0	392	767
22°	82.3	384	751
23°	80.6	376	736
24°	79.1	369	721
25°	77.9	362	708

tube. A similar investigation was also performed for patients undergoing surgery for the study of specific resistance.

In addition, we measured the bioelectronic factors of the various intravenous replacement solutions and blood components, such as lactated Ringer's solution, 5% glucose, normal saline, Hartmann-D (lactated Ringer's solution with 5% glucose), half saline with 5% glucose, EL#3 (Na 40 mEq/l, K 35 mEq/l, Cl 40 mEq/l, lactate 20 mEq/l, phosphate 15 mEq/l, glucose 50 g/l), packed red blood cells, fresh frozen plasma, CPD blood and plasma protein fraction.

Results are presented as mean ± standard error of mean (SEM), and statistical analysis was performed using a linear regression analysis.

Results

Arterial and venous blood and urine samples were taken from 20 healthy adults and their bioelectronic factors and other biochemical factors were immediately determined. The results are shown in table 2. Concerning bioelectronic factors, since the arterial and venous blood showed almost identical values, it would be logical to state that the normal redox potential

Table 2. Normal values of bioelectronic factors of arterial and venous blood and urine obtained from adult healthy men

	Arterial blood	Venous blood	Urine
pH	7.404 ± 0.026*	7.381 ± 0.027	5.689 ± 0.43
rH_2	23.0 ± 0.4	22.8 ± 0.6	19.0 ± 0.7
R (ohm)	195.6 ± 20.6	198.8 ± 22.0	47.3 ± 19.6
E (mV)	243.0 ± 12.6	237.6 ± 16.8	231.4 ± 15.6
I (mA)	1.27 ± 0.12	1.21 ± 0.15	5.86 ± 2.68
μW	310.9 ± 35.4	288.3 ± 47.8	1386.3 ± 705.6

* All values are expressed as mean ± SEM. n=20

(E) of arterial and venous blood is very close to 240 millivolts.

The values of pH, I (milliampere) and microwatts of urine deviated considerably from those of blood. The greater variations in urinary bioelectronic factors might be due to the urine volume fluctuation.

Fig. 3 illustrates the influence of O_2 inhalation on the arterial blood redox potential. No significant alterations were observed during O_2 inhalation.

The relationship between arterial specific resistance (R) and hematocrit is shown in fig. 4. A very close correlation was found between them and the coefficient of the correlation was 0.82. There was also good correlation (coefficient of correlation -0.82) between the R value represented on the log scale and electrolyte ($Na^+ + K^+ + Cl^-$) concentrations in urine as shown in fig. 5.

The measured values of bioelectronic factors of the various intravenous replacement solutions and blood components are summarized in table 3. The E and μW values of most of these solutions were higher than those of blood. Lactated Ringer's solution which is widely used as an extracellular fluid replacer showed very different values of the bioelectronic factors from those of blood. Especially its E (393 mV) and μW (2037 μW) were much higher than those of blood.

In order to keep E value of lactated Ringer's solution close to that of blood, reduced

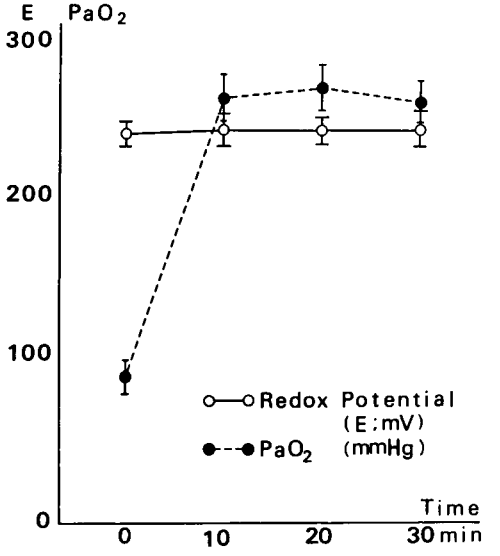

Fig. 3. The influence of O_2 inhalation on the value of arterial redox potential (n = 5)

glutathione was added. The results are shown in table 4. E and μW of lactated Ringer's solution were lowered with the addition of reduced glutathione (Tathion®; $[H_2N\text{-}CH\text{-}CH_2\text{-}CH\text{-}CONHCH_2COOH]$ Na) as shown in this table.

Discussion

As mentioned in the introduction, pH, rH_2 and E (redox potential) are all somehow

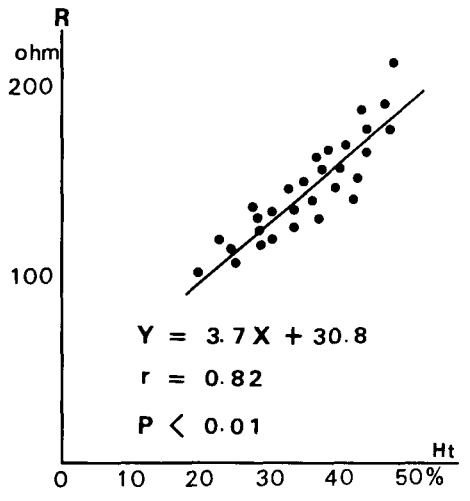

Fig. 4. Relationship between arterial specific resistance (R) and hematocrit (Ht) (n=30)

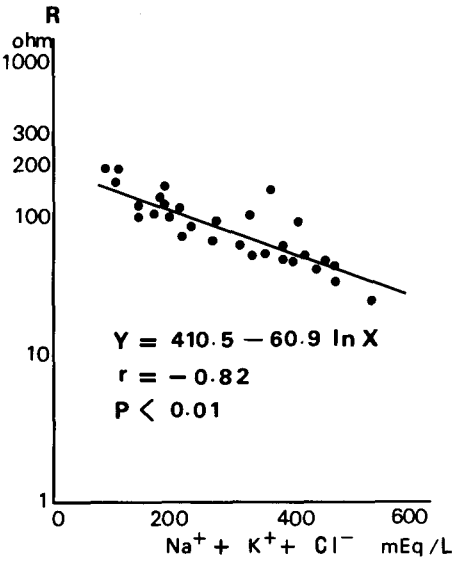

Fig. 5. Relationship between specific resistance (R) and electrolyte concentration in urine (n=30) (The R values are represented on the log scale.)

Table 3. The values of bioelectronic factors of the various intravenous replacement solutions and blood components

	pH	rH_2	R (ohm)	E (mV)	I (mA)	μW
Blood	7.40±0.03	23.0±0.4	195.6±20.6	243.0±12.6	1.27±0.12	310.9±35.4
Urine	5.68±0.43	19.0±0.7	47.3±19.6	231.4±15.6	5.86±26.8	1386.2±705.6
normal saline	6.14±0.41**	24.9±0.5	63.9±0.8	378.0±22.3	5.92±0.38	2246.0±269.3
L/R*	6.34±0.20	25.5±1.1	76.4±1.2	384.1±26.9	5.03±0.36	1946.2±27.2
5% glucose	4.12±0.48	23.0±0.7	21400±15564	440.2±44.8	0.02±0.002	14.2±9.0
Hartmann-D*	4.51±0.08	22.5±0.8	84.3±1.1	402.4±24.5	4.77±0.30	1926.0±230.0
KN-1A*	4.89±0.40	22.2±0.6	130.5±2.9	380.3±24.2	2.86±0.15	1111.2±114.9
EL#3*	5.43±0.09	22.2±0.5	147.3±2.4	337.1±14.5	2.29±0.11	772.4±156.6
PRC*	6.62±0.62	23.7±1.2	416.0±39.2	313.8±25.6	0.75±0.24	237.1±19.2
FFP*	7.17±0.42	24.8±1.1	73.0±9.2	313.8±21.2	4.30±0.36	1385.2±86.4
CPD blood	6.91±0.32	23.5±0.8	137.3±11.2	290.4±12.6	2.12±0.29	616.3±42.6
PPF*	6.93±0.52	27.6±1.4	77.2±5.8	412.2±25.2	5.34±0.42	221.4±12.6

* L/R = lactated Ringer's solution, Hartmann-D = lactated Ringer's solution with 5% dextrose KN-1A = half saline with 5% glucose, EL#3 = Na 40 mEq/L, K 35 mEq/L, Cl 40 mEq/L, lactate 20 mEq/L, phosphate 15 mEq/L, 5% glucose, PRC = packed red cells, FFP = fresh frozen plasma, PPF = plasma protein fraction,

** All values are expressed as mean ± SEM. n = 10

interrelated. Based on these interrelationships a diagram (pH–rH_2 diagram or bioelectronigram of VINCENT) was introduced as shown in fig. 6. In this diagram the E values are expressed in straight lines slanting towards the left. The redox line representing 240 mV passes through the intersection of pH=7.00 and rH_2=22.0. In this diagram point A (pH=7.40, rH_2=22.8 and E=240 mV) corresponds to the blood condition of good health. Point 1 and

Table 4. The influence of glutathione addition on the values of the bioelectronic factors of lactated Ringer's solution (100 ml)

glutathione (mg)	pH	rH_2	R (ohm)	E (mV)	I (mA)	μW
0	6.32±0.20*	25.5±1.0	76.4±1.2	384.1±26.9	5.03±0.36	1946.0±27.2
150	6.30±0.08	24.0±0.8	75.6±0.5	342.5±9.03	4.53±0.12	1552.5±80.6
300	6.28±0.20	23.2±0.4	75.4±0.7	320.5±5.1	4.25±0.08	1363.0±45.2
450	6.20±0.07	22.2±0.3	75.0±0.8	294.5±5.5	3.93±0.42	1157.1±32.6
600	6.15±0.06	21.6±0.7	74.8±0.4	278.1±5.5	3.72±0.36	1034.2±37.8

* All values are expressed as mean ± SEM. n=10

2 correspond to the physical conditions of normal saline and lactated Ringer's solution, respectively. Apparently they are more acidotic and oxidative compared to blood. The addition of reduced glutathione 600 mg to 100 ml of lactated Ringer's solution seems to be desirable to maintain the redox value in more acceptable state (point 3). Normal saline and lactated Ringer's solution are commonly used as extracellular fluid replacers, because of their resemblance of electrolyte constituents to those of ECF, however, their values of bioelectronic factors are rather different from those of ECF.

It is stated that the redox potential determines the velocity of the intracellular biochemical reactions. The enzyme activity is very sensitive to the physical and chemical factors of the milieu in which it occurs.[1,3] The maximal activity of any enzyme depends on its optimal pH value and the redox potential (E). The deviation of the bioelectronic factors of body fluids might induce the disturbance in the cellular biochemical reactions, and result in the deterioration of vital processes. The measurements of the bioelectronic factors of body fluids will therefore provide us with useful information for the treatment of deteriorated patients.

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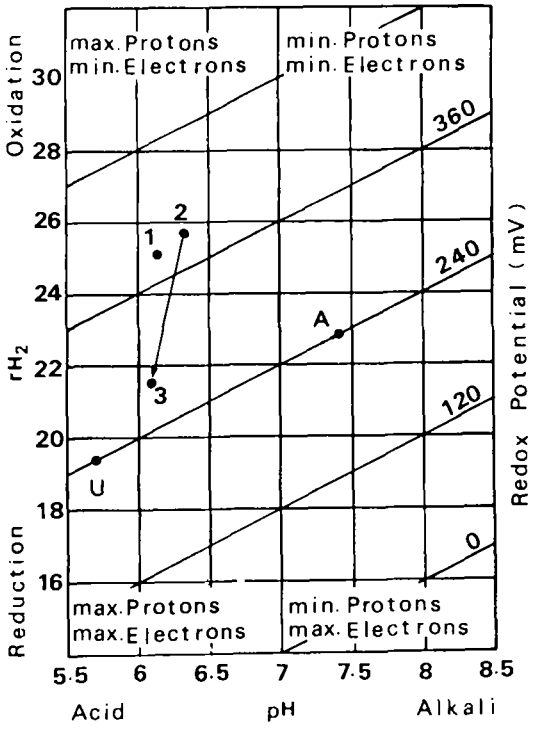

Fig. 6. pH rH_2 diagram (Bioelectronigram)
A. The blood condition of good health
U. The urinary condition of good health
1. The physical condition of normal saline
2. The physical condition of lactated Ringer's solution
3. The more acceptable state after addition of reduced glutathione 600 mg to 100 ml of lactated Ringer's solution

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