The concentration of cerebrospinal fluid potassium during systemic disturbances of acid-base metabolism

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SYNOPSIS A possible relationship between blood acid-base state and the concentration of cerebrospinal fluid potassium has been examined in patients with systemic disturbances of acid-base metabolism. Over the range of values studied it was not possible to demonstrate any significant correlation between these parameters.

A decrease in the concentration of cerebrospinal fluid (CSF) potassium has been demonstrated in patients after subarachnoid haemorrhage and a stroke (Sambrook, Hutchinson, and Aber, 1973). Although these patients also developed a systemic alkalosis no significant correlation could be demonstrated between changes in CSF potassium concentration and arterial blood acid-base values. In order to investigate further the possible relationship between arterial blood pH and CSF potassium a study has been made in patients with systemic disturbance of acid-base metabolism.

Patients Studied

Reference values for blood and CSF acid-base parameters and potassium concentration were obtained from 40 control patients who had a lumbar puncture performed during the course of routine neurological investigations but in whom no significant central nervous system pathology was subsequently demonstrated. Samples of CSF were rejected if the white cell count was greater than $4/\text{mm}^3$ or the protein concentration in excess of 40 mg/100 ml.

Ten patients with systemic acid-base disorders were studied (table II). Four patients had chronic renal failure and were observed during acute and subacute disturbance of acid base. Patients with primary hyperaldosteronism, Cushing's syndrome, and liver cirrhosis had stable blood acid-base values for at least seven days before obtaining simultaneous samples of blood and CSF whereas in the remaining three patients the abnormalities of acid base had developed acutely within 24 hours. The purpose of

the investigation was explained to patients or their relatives before permission for CSF examination was requested.

Methodology

Simultaneous samples of lumbar CSF and femoral arterial and antecubital venous blood were obtained for measurement of CSF and blood acid-base values and potassium concentration. Samples of CSF were withdrawn anaerobically into a glass syringe and sealed with a metal cap, the dead space of the syringe having first been filled with the patient's CSF before taking the full sample.

Measurements of arterial blood and lumbar CSF pH were made with a G.9027/2 microelectrode and PCO_2 with a direct reading E.5036 Severinghaus electrode using PHM 27 meter and gas monitor PHA 927b (Radiometer Company, Copenhagen). The G.9027/2 microelectrode was calibrated with BDH precision buffers (pH 6.850, 7.380, and 7.420) and the PCO_2 electrode with special gas preparations of 4 and 8% CO_2 . Analyses were performed within 20 minutes of taking samples. The bicarbonate concentration of arterial blood was derived from the Siggard-Anderson nomogram and for CSF it was calculated from the Henderson-Hasselbalch equation using a solubility coefficient for CO_2 in CSF of 0.0312 mmol/l and a pK value of 6.13 (the mean of values calculated by Alexander, Gelfand, and Lambertsen, 1961; Cowie, Lambie, and Robson, 1962; Mitchell, Carman, Severinghaus, Richardson, Singer, and Shnider, 1965; Alroy and Flenley, 1967).

The concentration of potassium in CSF and plasma was estimated by flame photometry using an EEL 150 clinical flame photometer.

Results

Reference values for blood and CSF acid-base measurements and potassium concentration established in 40 control patients are given in table I and agree well with the results of previous workers (Bradbury, Stubbs, Hughes, and Parker, 1963; Huang and Lyons, 1966). It is noteworthy that the mean values and range for CSF potassium were much smaller than those for plasma.

The biochemical findings in patients with systemic disturbances of acid-base are detailed in table II. The range of values for arterial blood pH was 7.15-7.51, actual blood $[\text{HCO}_3^-]$ 10-38 mmol/l and PaCO_2 2000-6800 Nm^{-2} (15-51 mm Hg) and for CSF pH 7.30-7.38, CSF $[\text{HCO}_3^-]$ 10.9-27.2 mmol/l and Pcsf CO_2 3066-7600 Nm^{-2} (23-57 mm Hg). Except in three patients values for CSF potassium concentration remained within the range established in control subjects and were not influenced by

Figs 1 and 2 Simultaneous values for CSF potassium concentration and (1) blood pH and (2) PaCO_2 in 10 patients with systemic disturbance of acid-base metabolism (31 estimations)

Parameter	Cerebrospinal Fluid	Blood/Plasma
pH	7.335 $\pm$ 0.02 (7.300-7.360)	7.410 $\pm$ 0.03 (7.370-7.450)
$[\text{HCO}_3^-]$ (mmol/l)	22.2 $\pm$ 1.3 (19.8-24.8)	25.8 $\pm$ 2.3 (23.0-29.4)
PCO_2 (Nm^{-2})	6240 $\pm$ 440 (5600-7200)	5426 $\pm$ 533 (4800-6400)
(mm Hg)	46.8 $\pm$ 3.3 (42-54)	40.7 $\pm$ 4.0 (36-48)
Potassium (mmol/l)	2.88 $\pm$ 0.13 (2.6-3.1)	3.95 $\pm$ 0.38 (3.4-4.7)

Table I Values for CSF and plasma acid-base parameters and potassium concentration in 40 control patients

Patient	Diagnosis	pH		Actual $[\text{HCO}_3^-]$ (mmol/l)		PCO_2 (Nm^{-2}) (mm Hg)		Potassium (mmol/l)	
		CSF	Blood	CSF	Blood	CSF	Blood	CSF	Blood/Plasma
1	G. P. Chronic renal failure*	7.315	7.190	16.0	12.0	4800 (36)	4400 (33)	3.2	5.7
2	A. B. Chronic renal failure*	7.375	7.150	18.0	11.0	4666 (35)	4266 (32)	2.8	4.0
3	M. S. Chronic renal failure*	7.325	7.470	26.0	35.0	7333 (55)	6399 (48)	3.0	4.8
4	R. T. Chronic renal failure*	7.340	7.280	21.2	16.5	5600 (42)	4800 (36)	2.9	4.9
5	A. B. Primary hyperaldosteronism*	7.335	7.480	27.2	38.0	7600 (57)	6800 (51)	2.8	1.9
6	J. B. Cushing's syndrome	7.380	7.510	26.0	34.0	6533 (49)	5866 (44)	2.8	2.5
7	J. E. Mandrax overdose*	7.300	7.300	23.4	24.6	7066 (53)	6800 (51)	2.8	4.2
8	E. W. Salicylate overdose	7.330	7.440	10.9	10.0	3066 (23)	2000 (15)	2.7	3.3
9	J. K. Liver cirrhosis	7.380	7.420	19.1	19.1	4800 (36)	4000 (30)	2.5	3.1
10	A. S. Gastroenteritis	7.355	7.330	22.0	20.8	5866 (44)	5333 (40)	2.9	4.1

Table II Diagnosis and values for CSF and plasma acid-base parameters and potassium concentration in 10 patients with systemic disturbance of acid-base metabolism¹

¹ Several measurements were made in six patients* during their illness and the tabulated values are those recorded during the period of maximum acid-base disturbance.

changes in either blood or CSF, pH, PCO_2 , or $[\text{HCO}_3^-]$ (figs 1 and 2). The mean concentration of CSF potassium in patients with values for blood pH below 7.40 was 2.93 ± 0.13 mmol/l and for pH 7.40 and above was 2.88 ± 0.25 mmol/l (not significantly different from values in controls). Values for plasma potassium ranged from 1.9 to 5.7 mmol/l.

Discussion

Changes in the concentration of plasma and extracellular fluid potassium occur with systemic disturbances of acid-base metabolism and are due to both renal and extrarenal mechanisms (Berliner, Kennedy, and Orloff, 1951; Keating, Weichselbaum, Alanis, Margraf, and Elman, 1953; Black, 1967). Since the concentrations of ions in cerebral extracellular fluid and CSF are similar (Fencl, Miller, and Pappenheimer, 1966) the possible influence of disturbances of systemic acid-base metabolism upon CSF potassium concentration has been studied. Measurements were made in patients with respiratory and metabolic alkalosis and acidosis and where possible several observations were recorded during the patient's illness. The results failed to show any consistent pattern of change in the concentration of CSF potassium over the range of blood and CSF acid-base parameters studied.

The absence of any demonstrable influence of blood pH upon CSF potassium may be due to two factors. First, an electrical potential difference exists between CSF and plasma which is sensitive to changes in blood pH, and second changes in blood pH are often accompanied by relatively small alterations in that of cerebrospinal fluid.

Tschirgi and Taylor (1958) and Held, Fencl, and Pappenheimer (1964) demonstrated that CSF was 4.5 m volts positive in relation to plasma and this potential difference increased during acidosis and decreased and became negative during alkalosis. An increase in CSF-plasma potential difference would oppose the movement of cations into the cerebral extracellular compartment whilst a decrease would oppose their exit. Thus in systemic acidosis an increased movement of potassium ions from intra- to extracellular fluid would be opposed by an increase in electrical potential difference. The reverse situation would occur in systemic alkalosis.

Changes in blood pH are associated with smaller changes in pH of CSF (Bradley and Semple, 1962; Pauli, Vorbürger, and Reubi, 1962; Mitchell *et al.*, 1965; Posner, Swanson, and Plum, 1965), and it is possible that the flux of potassium ions between cerebral extracellular fluid and cerebral parenchyma is influenced by changes in blood pH to a much smaller degree than in other tissues. In the patients

studied only three had values for CSF pH outside the range established in controls but even in these the concentration of CSF potassium was normal.

Carbon dioxide rapidly diffuses between blood and CSF and the possibility that the concentration of CSF potassium could be related to changes in PaCO_2 was examined. Although the concentration of CSF potassium was lowest (2.5 and 2.7 mmol/l) in the two patients with lowest values for PaCO_2 (2000 and 4000 Nm^{-2}) (15 and 30 mm Hg) there was no significant overall correlation between them.

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References

- Alexander, S. C., Gelfand, R., and Lambertsen, C. S. (1961). The pK^1 of carbonic acid in cerebrospinal fluid. *J. biol. Chem.*, **236**, 592-596.
- Alroy, G. G., and Flenley, D. C. (1967). The acidity of the cerebrospinal fluid in man with particular reference to chronic ventilatory failure. *Clin. Sci.*, **33**, 335-343.
- Berliner, R. W., Kennedy, T. J., Jr., and Orloff, J. (1951). Relationship between acidification of the urine and potassium metabolism. *Amer. J. Med.*, **11**, 274-282.
- Black, D. A. K. (1967). *Essentials of Fluid Balance*, 4th ed. Blackwell, Oxford.
- Bradbury, M. W. B., Stubbs, J., Hughes, I. E., and Parker, P. (1963). The distribution of potassium, sodium, chloride, and urea between lumbar cerebrospinal fluid and blood serum in human subjects. *Clin. Sci.*, **25**, 97-105.
- Bradley, R. D., and Semple, S. J. G. (1962). A comparison of certain acid-base characteristics of arterial blood, jugular venous blood and cerebrospinal fluid in man, and the effect on them of some acute and chronic acid-base disturbances. *J. Physiol. (Lond.)*, **160**, 381-391.
- Cowie, J. A., Lambie, A. T., and Robson, J. S. (1962). The influence of extracorporeal dialysis on the acid-base composition of blood and cerebrospinal fluid. *Clin. Sci.*, **23**, 397-404.
- Fencl, V., Miller, T. B., and Pappenheimer, J. R. (1966). Studies on the respiratory responses to disturbances of acid-base balance, with deductions concerning the ionic composition of cerebral interstitial fluid. *Amer. J. Physiol.*, **210**, 459-472.
- Held, D., Fencl, V., and Pappenheimer, J. R. (1964). Electrical potential of cerebrospinal fluid. *J. Neurophysiol.*, **27**, 942-959.
- Huang, C. T., and Lyons, H. A. (1966). The maintenance of acid-base balance between cerebrospinal fluid and arterial blood in patients with chronic respiratory disorders. *Clin. Sci.*, **31**, 273-284.
- Keating, R. E., Weichselbaum, T. E., Alanis, M., Margraf, H. W., and Elman, R. (1953). The movement of potassium during experimental acidosis and alkalosis in the nephrectomized dog. *Surg. Gynec. Obstet.*, **96**, 323-330.
- Mitchell, R. A., Carman, C. T., Severinghaus, J. W., Richardson, B. W., Singer, M. M., and Shnider, S. (1965). Stability of cerebrospinal fluid pH in chronic acid-base disturbances in blood. *J. appl. Physiol.*, **20**, 443-452.
- Pauli, H. G., Vorbürger, C., and Reubi, F. (1962). Chronic derangements of cerebrospinal fluid acid-base components in man. *J. appl. Physiol.*, **17**, 993-998.
- Posner, J. B., Swanson, A. G., and Plum, F. (1965). Acid-base balance in cerebrospinal fluid. *Arch. Neurol.*, **12**, 479-496.
- Sambrook, M. A., Hutchinson, E. C., and Aber, G. M. (1973). Metabolic studies in subarachnoid haemorrhage and strokes. II. Serial changes in cerebrospinal fluid and plasma urea, electrolytes and osmolality. *Brain*, **96**, 191-202.
- Tschirgi, R. D., and Taylor, J. L. (1958). Slowly changing bioelectric potentials associated with the blood-brain barrier. *Amer. J. Physiol.*, **195**, 7-22.