ACID-BASE CHANGES IN CEREBROSPINAL FLUID AND BLOOD, AND BLOOD VOLUME CHANGES FOLLOWING PROLONGED HYPERVENTILATION IN MAN

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SUMMARY
Fifty patients with cerebral apoplexy (stroke) were randomly allocated to treatment with prolonged artificial hyperventilation (3 days) instituted in the acute phase of the stroke. In 24 patients, artificial ventilation was maintained at hypocapnic levels (\(P_{CO_2}\) 25 mm Hg) while in the remainder (26 patients) normocapnia was obtained by adding \(CO_2\). A comparable group (21 patients) which was not treated by artificial ventilation served as controls. This control group showed a constant active hyperventilation during the first 12 days (\(P_{CO_2}\) 32-34 mm Hg). A constant decrease in c.s.f. bicarbonate was found associated with an almost normal calculated c.s.f. pH. Initially, hypocapnic hyperventilation caused a marked increase in c.s.f. pH which had returned to normal 30 hours later in consequence of a decrease in c.s.f. bicarbonate. The introduction of normocapnic hyperventilation in these spontaneously hyperventilating patients produced an immediate acid shift of c.s.f. pH. An increase in c.s.f. bicarbonate resulted in a stable and almost normal c.s.f. pH 30 hours later. There was no sign of metabolic compensation in the blood, the standard bicarbonate remaining essentially unaltered in all groups during the 12 days of observation. During and after artificial hyperventilation, a progressive decrease in haemoglobin and serum protein concentrations suggested a blood volume increase and an extravasation of protein. Transient hyponatraemia (4.1 m.mol/1.), hypokalaemia (0.32 m.mol/1.) and water retention were seen during artificial ventilation.

Following acutely induced changes in alveolar ventilation there are inverse proportional changes of pH and \(P_{CO_2}\), with an unchanged bicarbonate concentration in both blood and cerebrospinal fluid (c.s.f.). However, when the respiratory changes are prolonged, further alterations take place in the acid-base balance of the body. For example, it has been shown that the organism will tend to return the c.s.f. pH to within normal limits by a proportional change in the bicarbonate concentration (Severinghaus et al., 1963; Messeter and Siesjö, 1971). Prolonged changes in the acid-base balance of the blood are also said to be compensated for by an alteration in the bicarbonate concentration mediated through the kidneys (metabolic compensation). A knowledge of the rates of these compensatory changes could be of importance in the clinical use of artificial ventilation.

A controlled clinical trial of the therapeutic effect of prolonged artificial hyperventilation in acute cerebral apoplexy (stroke) (Christensen et al., 1973a), afforded the opportunity to study some of these compensatory mechanisms, both as regards their magnitude and their time relationship. In addition to these metabolic effects of sustained hypocapnia, an evaluation of the influence of prolonged artificial hyperventilation on the blood volume (as suggested from changes in the concentrations of haemoglobin, protein and electrolytes) was performed.

MATERIAL
Seventy-one patients with cerebral apoplexy (stroke) were studied. After classification based on both the clinical findings and carotid angiography, 50 patients were treated with artificial hyperventilation, and 21 patients without. Following random allocation, the ventilated patients were maintained at either hypocapnic (24 patients) or normocapnic (26 patients) levels of \(P_{CO_2}\). Ventilation was started within the first 24 hours after the onset of the symptoms of apoplexy. On admission, none of the patients studied showed any signs of cardiac decompensation or of pulmonary insufficiency.
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Detailed information on the patients is given in table I. Only patients with severe strokes were selected for the clinical trial. The three treatment groups were comparable both as regards age, disease and clinical course (Christensen et al. 1973a).

Arterial blood acid-base parameters, and the concentrations of haemoglobin, serum protein and serum electrolytes were studied in all patients. In 46 patients, a non-haemorrhagic c.s.f. sample was obtained for the determination of bicarbonate concentration from 13 of the hypocapnic group, 17 of the normocapnic group, and 16 of the group not treated by ventilation. C.s.f. samples contaminated with blood were discarded (4 patients). For comparison, baseline values of PaCO₂ and c.s.f. bicarbonate concentration were measured in 13 normal adults with a provisional diagnosis of lumbar disc herniation. Samples of arterial blood and c.s.f. were taken for analysis during myelography.

**METHODS**

**Artificial ventilation.**

General anaesthesia was induced in each of the ventilated patients with pentobarbitone 240–300 mg i.v. After an initial dose of tubocurarine, the patients were intubated either through the nasotracheal or the orotracheal route and then ventilated by a time-cycled ventilator (Barnet Mk II (29 cases) and Mk III (21 cases)). Moderate hyperventilation (PaCO₂ about 25 mm Hg) was achieved with a mixture of air and oxygen (ratio 7:1) to give 30% oxygen. In those patients selected for normocapnic hyperventilation, about 3% carbon dioxide was added to the inspiratory gas mixture to increase PaCO₂ to normocapnic levels in combination with a comparable degree of mechanical hyperventilation. The details of the manner in which artificial hyperventilation was employed are given in table II. To obtain relatively constant PaCO₂ values in the presence of unchanged tidal volumes during the 3-day ventilation.
period the added carbon dioxide was decreased gradually (average values during day 1: 2.9%; day 2: 2.5%; and day 3: 2.2%). The tidal volume used initially in both groups averaged 10 ml/kg body weight. The inspired air was humidified using an ultrasonic nebulizer with a drip rate to give a water content corresponding to 80–85% relative humidification at 37°C (Herzog, Norlander and Engstrom, 1964).

To facilitate ventilation and to obtain maximal muscular relaxation, pentobarbitone and tubocurarine were given at intervals during the first 48 hours of ventilation. The amount given was decreased during the second day, and this medication was discontinued after 48 hours. During the third day small doses of chlorpromazine and pethidine were given repeatedly. Some of the patients required assisted ventilation for varying periods after cessation of the hyperventilation treatment, while 8 patients died during the treatment period. These patients are not considered in the present paper.

**Fluid balance.**

The ventilated patients had intravenous fluid only during the first 5 days of treatment, whereas the non-ventilated patients had both intravenous (about 55%) and oral (about 45%) fluids. The urinary output per hour was monitored, thus allowing the rapid correction of fluid balance. The major part of the non-colloid infusion given to each patient was dextrose 5%, the remainder being physiological saline. Average values for the fluid balance in the three treatment groups during and after the ventilation periods, are given in table III.

**Analyses.**

C.s.f. bicarbonate was analysed using the Conway method (Conway, 1962). As the c.s.f. changes might not have reached a steady state suboccipital puncture was made initially, otherwise lumbar puncture was employed.

The arterial Pco2, pH, standard bicarbonate and oxygen saturation, were closely monitored in all patients, especially during artificial hyperventilation. The Astrup technique was used in most cases, but in some a teflon covered glass electrode was used for the PaO2 determinations. Oxygen saturation was determined spectrophotometrically. All PaO2 and arterial pH values (except in fig. 4) were corrected for body temperature (Severinghaus, 1966). Haemoglobin concentrations were determined colorimetrically, and protein concentrations were analysed by the biuret method. Sodium and potassium concentrations in serum and urine were determined using flame photometry.

**RESULTS**

The average values of the acid-base parameters determined in c.s.f. and in blood in the three different treatment groups are summarized in figures 1–3. The c.s.f. bicarbonate was estimated initially, and on the third and sixth days. Arterial acid-base status was determined regularly during the first 12 days after the onset of the apoplectic episode. To evaluate the degree of compensation in c.s.f., its pH has been calculated, using the Henderson-Hasselbalch equation. pK1 and S (solubility of CO2) values were taken from the work of Mitchell, Herbert and Carman (1965). C.s.f. bicarbonate was measured, and c.s.f. Pco2 calculated as PaO2 + ΔPco2 (ΔPco2 is the difference in Pco2 between c.s.f. and arterial blood). A Δ Pco2 value of 8 mm Hg found in normal man (Severinghaus et al., 1963) has been used for the calculations.

In 10 of the hyperventilated patients (5 hypocapnic and 5 normocapnic) repeated estimations of the

| Table III. Fluid balance during the first 5 days after onset of cerebral apoplexy (stroke) in 71 patients treated with or without prolonged artificial hyperventilation (3 days). |
|-------------------------------|-------------------------------|-------------------------------|
| **Hypocapnic ventilated**     | **Normocapnic ventilated**    | **Spontaneously breathing**   |
| **(n=24)**                    | **(n=26)**                    | **(n=21)**                    |
| **Day**                       | **total colloids**            | **input colloids**           | **total colloids** | **balance** | **total colloids** | **input colloids** | **balance** |
| 1                             | 3446                          | 910                          | +786                     | 3731         | 827             | +572           | 1743        | 0           | +140         |
| 2                             | 3077                          | 879                          | +106                     | 3751         | 945             | +646           | 1555        | 0           | -363         |
| 3                             | 3152                          | 852                          | +122                     | 3006         | 702             | +300           | 1416        | 0           | -632         |
| 4                             | -535                          | -172                         | -215                     | 2474         | +1518          | -855           |             |             |              |
| 1→3                           | 2641                          | +1014                        |                          |              |                 |                |             |             |              |

*aminoacids (75%), blood (12%) and protein (13%)*
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FIG. 1. The mean values of arterial Pco₂, pH, and standard bicarbonate from 24 patients with cerebral apoplexy (stroke) treated with hypocapnic hyperventilation, instituted during the first day after the attack and continued for 3 days. The mean values of c.s.f. bicarbonate are from 13 of these patients, and c.s.f. pH is calculated according to the Henderson-Hasselbalch equation using a (c.s.f.-arterial) Pco₂ of 8 mm Hg. Bars indicate SE. The asterisks indicate mean values found in 13 normal patients.

c.s.f. bicarbonate concentration were made during the 72-hour ventilation period. The variations of c.s.f. bicarbonate, Pao₂ and calculated c.s.f. pH (see above) are summarized in figure 4.

From the measured oxygen saturations, the Pao₂ was calculated using the individual pH, Pco₂ and haemoglobin values (Severinghaus, 1966). In the hypocapnic group, Pao₂ averaged 92 mm Hg (SD 33) during the first 24 hours of ventilation. In the normocapnic group, the comparable value was 131 mm Hg (SD 39), whereas during spontaneous respiration a mean of 122 mm Hg (SD 40) was noted, both values being significantly greater than during hypocapnia.

The average values for haemoglobin concentration before treatment and on the third and sixth day after the onset of the stroke are given in figure 5. In the non-ventilated group a normal, and essentially unchanged, haemoglobin concentration was found throughout. In the 50 ventilated patients, there was a statistically significant and progressive decrease in haemoglobin concentration. In 33 of the 50 patients, no blood transfusion was given during the 6 days, and consequently they showed the most pronounced decrease of haemoglobin (after 3 days: 1.23 g/100 ml and after 6 days: 2.54 g/100 ml). No statistically significant differences were found between the haemoglobin concentrations of the hypocapnic and normocapnic patients.

The changes in serum protein concentration were similar to the haemoglobin changes. They were essentially unchanged during spontaneous respira-
tion, but showed a highly significant, although not progressive, decrease during and after artificial hyperventilation (both hypocapnic and normocapnic groups). The changes in haemoglobin concentration and serum protein concentration found in those patients who had neither blood transfusions nor protein infusions during the first 6-day period of treatment are summarized and compared in table IV.

The serum sodium concentration showed a significant mean decrease of about 4 m.mol/l. during the second day of hyperventilation (both hypocapnic and normocapnic groups) compared with the initial value (fig. 6). Three days later, only a slight and insignificant decrease was found. In the non-ventilated group, the serum sodium concentration was normal and unchanged throughout. Figure 6 details the concomitant changes in potassium concentration. There was a significant decrease in serum potassium concentration during the second day of hyperventilation (both hypocapnic and normocapnic groups), a small but insignificant decrease 3 days later, and an unchanged potassium concentration in non-ventilated patients. No differences were found between the hypocapnic and normocapnic ventilation groups in respect of the changes in sodium and potassium concentrations.

**DISCUSSION**

**Acid-base changes.**

As the three treatment groups in the present study are comparable, the group which was not ventilated may serve as control. A moderate and constant degree of spontaneous hyperventilation (Paco2 32–34 mm Hg) was typical of this group during the first
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Haemoglobin concentration and cumulated fluid balance in patients with cerebral apoplexy (stroke) treated with or without prolonged artificial hyperventilation for 3 days. Fifty patients received hyperventilation. Thirty-three of these patients had no blood transfusions during the first 6 days. Twenty-one patients received no artificial ventilation. Bars indicate SE.

**Fig. 5.** Haemoglobin concentration and cumulated fluid balance in patients with cerebral apoplexy (stroke) treated with or without prolonged artificial hyperventilation for 3 days. Fifty patients received hyperventilation. Thirty-three of these patients had no blood transfusions during the first 6 days. Twenty-one patients received no artificial ventilation.

**Fig. 6.** Serum concentration and urinary output of sodium and potassium in patients with cerebral apoplexy (stroke) treated with or without prolonged artificial hyperventilation for 3 days. Fifty patients received hyperventilation. Twenty-four of these were hypocapnic and 26 normocapnic. Twenty-one patients received no artificial ventilation. Bars indicate SE.

**Table IV.** Changes in haemoglobin concentration and serum protein concentration during, and after, prolonged artificial ventilation (3 days) compared with spontaneous respiration. Only patients who had neither blood transfusions nor protein infusions are included.

<table>
<thead>
<tr>
<th></th>
<th>Artificial Ventilation</th>
<th>Spontaneous Respiration</th>
<th>Comparison of the Relative Changes*</th>
</tr>
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<tbody>
<tr>
<td><strong>Haemoglobin concentration (g/100 ml)</strong></td>
<td>Initial</td>
<td>Day 3</td>
<td>Day 6</td>
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<tr>
<td>Artificial ventilation</td>
<td>Mean</td>
<td>14.48</td>
<td>13.30</td>
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<tr>
<td>SD</td>
<td>1.73</td>
<td>1.42</td>
<td>0.69</td>
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<td>n=16</td>
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<tr>
<td>Spontaneous respiration</td>
<td>Mean</td>
<td>14.91</td>
<td>14.73</td>
</tr>
<tr>
<td>SD</td>
<td>1.43</td>
<td>1.12</td>
<td>0.88</td>
</tr>
<tr>
<td>n=12</td>
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<td></td>
</tr>
<tr>
<td><strong>Serum protein concentration (g/100 ml)</strong></td>
<td>Initial</td>
<td>Day 3</td>
<td>Day 6</td>
</tr>
<tr>
<td>Artificial ventilation</td>
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<td>15.14</td>
<td>13.17</td>
</tr>
<tr>
<td>SD</td>
<td>0.67</td>
<td>1.10</td>
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<tr>
<td>Spontaneous respiration</td>
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<td>13.93</td>
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<tr>
<td>SD</td>
<td>1.21</td>
<td>1.28</td>
<td>1.25</td>
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</table>

* Student t-test; n.s.=not significant (P > 0.1)
12 days after the onset of the stroke (fig. 3). The mechanism of this spontaneous hyperventilation in patients with severe stroke is still unknown, although there is some evidence to suggest a metabolic drive (c.s.f. acidosis) (Zupping, Kaasik and Raudam, 1971; Christensen et al., 1973b). In this study a significantly decreased and stable c.s.f. bicarbonate concentration was found during the first 6 days, followed by a slightly alkaline, and essentially unchanged, calculated c.s.f. pH. Thus, an almost complete c.s.f. pH adaptation had taken place during the first day after the apoplectic attack. In this context it has to be noted that the average value of c.s.f. bicarbonate found in the 13 normal patients (23.6 mmol/l.) gave a calculated c.s.f. pH of 7.32 which is in agreement with normal values found by Severinghaus and his co-workers (1963). Regarding the acid-base balance in arterial blood, no metabolic compensation, as assessed by the unchanged pH and standard bicarbonate, was found throughout 12 days of active hyperventilation.

Sustained hypocapnia is a rather uncommon clinical condition, but at high altitude non-acclimatized man will hyperventilate for several days because of hypoxia. The induced changes in the c.s.f. acid-base balance at high altitude have been reported by Severinghaus and his co-workers (1963). They found a rapid reduction of c.s.f. bicarbonate after 2 days, probably brought about by active transport across the blood-brain barrier, thus restoring the c.s.f. pH to normal. During sustained high altitude hypocapnia, the same rapid control of pH was not found in the blood. The compensatory renal regulation of plasma bicarbonate concentration has been reported to last from weeks to months (Chiodi, 1957; Dill, Talbott and Consolazio, 1937; Houston and Riley, 1947; Hurtado and Aste-Salazar, 1948). Severinghaus and his co-workers (1963) found unchanged standard bicarbonate values in plasma during 8 days of sustained hypocapnia (PaCO$_2$ about 30 mm Hg), accompanied by an alkalotic arterial pH (7.485). However, in another high altitude study, Severinghaus and his co-workers (1966) found a partial metabolic compensation in blood after 3–5 days of sustained hypocapnia.

The same rather slow and incomplete metabolic compensation in blood was found experimentally when adequately oxygenated rats were exposed to hypercapnia (PaCO$_2$ increase of about 32–40 mm Hg) for 2 months (Reichart et al., 1972). In clinical conditions involving hypercapnia, a more rapid increase of standard bicarbonate is found normally (Møller, 1959). However, such situations often involve a marked and progressive hypercapnia as a result of severe ventilatory insufficiency.

A more pronounced degree of hypocapnia (PaCO$_2$ 25 mm Hg) sustained for 3 days by passive hyperventilation influenced the c.s.f. acid-base status markedly (fig. 1). Because of the free passage of gaseous CO$_2$ across the blood-brain barrier, complete CO$_2$ equilibrium will be achieved in some 30 min (Bradley, Semple and Spencer, 1965). As a result, c.s.f. pH will increase. Three days later, a complete pH adaptation in the c.s.f. had taken place, as a result of the decrease in c.s.f. bicarbonate. In five of the patients studied, the c.s.f. acid-base status was measured repeatedly during this 3-day ventilation period (fig. 4, upper half). The sustained hypocapnia was accompanied by a significant decrease of c.s.f. bicarbonate, this being most pronounced during the first 4 hours of ventilation. Taking the return of c.s.f. pH to a stable value, as an indication of complete pH adaptation, a half life of approximately 6 hours was found, the adaptation being complete within 30 hours. No metabolic compensation was observed in arterial blood during the period of ventilation. After discontinuing the hyperventilation, all the acid-base variables studied approached the values found in the group not treated by ventilation (fig. 1).

As already mentioned, the stroke patients had a lowered c.s.f. bicarbonate because of spontaneous hyperventilation. In these patients, the introduction and maintenance of normocapnic conditions in the blood for 3 days caused an immediate acidic shift of the c.s.f. pH (fig. 2). Thus, a rapid return of c.s.f. PaCO$_2$ to within normal limits (a state of relative "hypercapnia" in these patients) caused a c.s.f. acidosis. Three days later, the c.s.f. pH had returned to normal following normalization of c.s.f. bicarbonate concentration. In figure 4 (lower half), the detailed response to increased PaCO$_2$ is illustrated. It was noted that a partial c.s.f. pH adaptation to hypocapnia was present before the ventilation treatment was started (lowered c.s.f. bicarbonate concentration). The sustained normocapnia was followed by an increase in c.s.f. bicarbonate concentration, giving a stable but still acid c.s.f. pH after about 30 hours. This lack of complete c.s.f. pH normalization, following a sustained PaCO$_2$ increase, has also been found by others (Huang and Lyons, 1966). After cessation of induced normocapnic ventilation, all variables studied approached the values found in the group who breathed spontan-
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previously, except for the standard bicarbonate, which showed a statistically significant increase in spite of the spontaneous hyperventilation present. This may probably be explained by a more rapid compensation in blood following hypercapnia than following hypocapnia. In this context it must be emphasized that none of the patients showed signs of renal insufficiency, and that the urinary output would allow a daily renal loss of at least 100 m.mol bicarbonate.

The c.s.f. pH has been calculated from the Henderson-Hasselbalch equation using a ΔPco₂ (difference between c.s.f. and arterial blood) of 8 mm Hg (Severinghaus et al., 1963). In another study of normal man, a ΔPco₂ of 9.4 mm Hg was found (Bradley and Semple, 1962). A value of 8 mm Hg has been reported in patients with severe head injuries (Katsurada, Sugimoto and Onji, 1969), whereas a value of 5 mm Hg has been found in moderately hyperventilating apoplectics (Zupping, Kaasik and Raudam, 1971). Pronounced hypocapnia is normally followed by an increase of ΔPco₂ (Leusen and Demeester, 1964). All these apparent discrepancies might be explained by: (a) differences in CO₂ production (cerebral blood flow and metabolism) between normal and damaged brain; (b) c.s.f. sampling from different levels of the cerebrospinal axis, and (c) non-steady state conditions. In figure 4 (upper half) two different ΔPco₂ values have been used: 8 and 12 mm Hg. Using 8 mm Hg gives a normal pH when adaptation is complete, whereas 12 mm Hg gives an acid c.s.f. pH after 30 hours (compare the lack of complete adaptation following normocapnia in fig. 4, lower half). Direct measurements of c.s.f. pH in apoplectics have shown normal, or slightly alkaline, values (Zupping, Kaasik and Raudam, 1971). Finally, it should be mentioned that the increase in c.s.f. lactate concentration was similar in all three groups studied (Christensen et al., 1973b).

It was noted in those patients subjected to hypocapnic hyperventilation that in spite of the unchanged tidal volumes employed (table II) a statistically significant rise of 3 mm Hg in PaCO₂ was found (fig. 1). Correction for the average fall of 1.1°C in body temperature during the same period would exaggerate this difference even more. An explanation for this increase in PaCO₂ could be an increase in physiological deadspace following 3 days of positive pressure ventilation (Askrog et al., 1964). However, the high incidence of pulmonary complications might well be the major factor responsible (Christensen et al., 1973a). The same observation was made in the patients subjected to normocapnic ventilation, where the added carbon dioxide per cent had to be decreased gradually to maintain an unchanged PaCO₂ while using unchanged tidal volumes for the 3 days.

Blood volume changes.

On admission all the patients studied had haemoglobin values within the normal range (fig. 5). Signs of dehydration were not present at that time. The marked and progressive anaemia, found among all the ventilated patients during the course of the first 6 days, cannot be explained simply as a result of a fluid overload (fig. 5). Although the anaemia could be related to the positive fluid balances present initially, this cannot be the explanation 3 days later, when a further fall in haemoglobin concentration occurred in spite of a negative fluid balance. Thus, the anaemia must, in some way, be related to the artificial hyperventilation, and not to the PaCO₂ changes. Hyperoxaemia may both decrease erythropoiesis (Tinsley et al., 1949) and increase erythrocyte destruction (Landaw, Leon and Winchell, 1970). In the present study, neither the short time course, nor the calculated PaCO₂ would support such an explanation. Drug-induced haemolysis would be an unlikely cause, as no gross signs of haemolysis were found, although the haptoglobin content was not examined systematically.

The progressive anaemia could possibly be the result of an increase in blood volume induced by the anaesthetics and the positive pressure ventilation. Experimentally, it has been shown that thiopentone causes sequestration of red cells, and a protein loss (O'Brien and Heath, 1968). Morgan and co-workers (1966) and Morgan, Crawford and Gunteroth (1969) found that the circulatory effects of positive pressure ventilation were related to its effect on the venous return, and suggested a compensation brought about by expansion of the blood volume. Conversely, Straub and Buhlmann (1970) found haemococoncentration during short-term active hyperventilation. The suggested blood volume increase was still present 3 days after cessation of artificial ventilation.

The changes observed in the serum protein concentration are essentially the same as those noted in haemoglobin concentration, suggesting similar causes, for example anaesthetics (Bond and Parsons, 1970) and artificial ventilation. In patients who had neither blood transfusion nor protein infusion, the relative decrease in serum protein concentration
was found to be significantly greater than the decrease in haemoglobin concentration during artificial ventilation (table IV). This implies that protein has been lost from the circulating blood volume. A probable explanation would be capillary diffusion augmented by the increased hydrostatic pressure associated with positive pressure ventilation. This extravasation might take place primarily in the lungs.

It has been shown that artificial ventilation can cause a decrease in urinary output. This has been related both to a decreased cardiac output (Baratz, Philbin and Patterson, 1971), and to an increased excretion of antidiuretic hormone (Murdaugh, Sicker and Manfredi, 1959). In the patients in this study, a sustained arterial hypotension followed the artificial ventilation (Christensen et al., 1973a), with a simultaneous positive fluid balance (table III). In a retrospective study, Sladen, Laver and Fontopoulos (1968) found a similar degree of water retention during artificial ventilation, accompanied by a decrease in serum sodium concentration of 5.8 m.mol/l. The present renal losses of sodium and potassium, both during, and after ventilation, were all within normal limits (fig. 6). It is concluded that the transient hyponatraemia and hypokalaemia found during artificial ventilation are the result of induced water retention.

CLINICAL COMMENTS

When artificial hyperventilation is prolonged for more than 1 or 2 days, a complete, or almost complete c.s.f. pH adaptation can be expected. Consequently, the therapeutic use of respiratory alkalosis in acute brain disorders characterized by metabolic acidosis (Lassen, 1966) will only cause a transient c.s.f. alkalosis. To obtain a constant degree of hypocapnia during prolonged hyperventilation the alveolar ventilation has to be increased gradually. However, the assumption of a linear relationship between PaCO₂ increase and time is not justified by the present study nor supported by clinical experience.

Following discontinuation of prolonged hyperventilation an abrupt increase (or even restoration to normal) of the PaCO₂ invariably results in a c.s.f. acidosis: a sudden increase of c.s.f. Pco₂ accompanied by a slow increase of c.s.f. bicarbonate (Brown, 1950). As this might be especially dangerous in a brain-damaged patient, the weaning of such patients from ventilator therapy should only allow gradual increases of PaCO₂. Furthermore, the patient will be forced to hyperventilate actively until respiratory alkalosis of c.s.f. pH has taken place (Brown et al., 1948).

As artificial ventilation causes an increase in blood volume, water retention, and extravasation of protein, a condition of reduced osmolality might be expected. Since it has been shown that c.s.f. and serum remain in osmotic equilibrium (Stueck and Fisher, 1961), the treatment of patients with acute brain lesions by artificial hyperventilation should also involve the use of measures to reduce cerebral oedema (diuretic, hyperosmolar solutions and steroid therapy).

REFERENCES


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