FLUID AND ELECTROLYTE BALANCE FOLLOWING CRANIOTOMY*

BURTON L. WISE, M.D.

Department of Neurological Surgery, University of California School of Medicine, and Neurosurgical Service, Fort Miley Veterans Administration Hospital, San Francisco, California

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METABOLIC balance studies, such as those performed by Moore and his co-workers, have clarified the aberrations of fluid and electrolyte metabolism that occur during and following surgical procedures. The data thus obtained provided a rational basis for fluid and electrolyte administration during the operative and postoperative periods.

There are at least two important reasons for such investigations in patients with intracranial lesions. First, the electrolyte content of intravenous fluids, and possibly of body fluids, affects the cerebrospinal fluid pressure in animals and in man. Secondly, lesions in certain areas of the brain are associated with unusual abnormalities of electrolyte metabolism, e.g., “cerebral salt wasting” and hypernatremia and hyperchloremia.

In this paper, the results of metabolic balance studies in 2 patients following craniotomy and in 1 patient after ventriculography will be presented and studies in 5 other patients following craniotomy will be mentioned. In addition, 2 instances of marked hyponatremia which occurred after the removal of pituitary tumors will be described.

METHODOLOGY

The oral intake data were estimated from standard tables. Moore and Ball stated that in their studies calculated intake data were close to the values obtained by analysis of the diet.) Sodium and potassium in urine and serum were measured on a Baird flame photometer with lithium as the internal standard.

The other determinations include 24-hour urinary excretion of nitrogen, 17-ketosteroids and free corticoids, the concentration of eosinophils in peripheral blood, and the serum chloride concentration and carbon dioxide combining power.

In Cases 1 and 2, in which balance data were fairly complete, the charting has been done according to the method of Moore and Ball. The intake is charted upward from the base line, the output downward from the intake line. The difference is the net balance, which, if positive, is cross-lined above

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the base line, if negative, is colored black below the base line. Thus, the intake, output, and net balance are visible at a glance. The other charts are explained in the legends.

CASE REPORTS

Case 1. A 12-year-old boy entered the University of California Hospital on Nov. 26, 1954. In September 1946 and again in March 1947, the patient had undergone resection of a cystic cerebellar astrocytoma, followed by postoperative radiation therapy. He remained well from 1947 to October 1953, when occasional morning vomiting appeared. Subsequently, intermittent headaches, fatigability and ataxic gait developed.

On admission the significant clinical findings were underaction of the left lower face, a left extensor toe response (Babinski), and a tendency to fall to the left.

On Dec. 5, 1954 suboccipital craniectomy was performed, and a cerebellar astrocytoma extending into the cisterna magna was partially removed.

Except for hyperthermia, which persisted for several weeks, the patient’s postoperative course was uneventful.
FLUID AND ELECTROLYTE BALANCE AFTER CRANIOTOMY

Metabolic Studies. The data of the balance study, charted in Fig. 1, demonstrated a metabolic response similar to that occurring after general surgical operations. During the immediate postoperative period, the nitrogen and potassium balances were negative and the sodium balance was positive. In several days, these trends were reversed. Positive potassium balance began on the 4th postoperative day, positive nitrogen balance on the 6th day, and negative sodium balance on the 7th day.

Oral feedings were begun on the 4th postoperative day, using a formula consisting of skimmed milk powder, banana flake and Meritene. Accurate analysis of this formula, which was developed by Pickering, had been previously performed.

During the immediate postoperative period, appreciable quantities of sodium were administered (see Fig. 1) because of the tendency of electrolyte-free intravenous fluids to increase the cerebrospinal fluid pressure, and cause brain swelling.

Fig. 2. Case 2. From above downward (left): nitrogen balance, potassium balance, sodium balance, 17-ketosteroid excretion, corticoid excretion and blood eosinophil concentration. On the right side of the chart are listed the preoperative data of glucose tolerance test, serum electrolyte concentration, basal metabolic rate, I" uptake, blood eosinophil response to ACTH, pituitary gonadotropin excretion, and hypertonic saline test (Hickey-Hare). Postoperative serum sodium concentrations are listed in text description of case.
The other noteworthy point is the fall in serum sodium concentration to 133 mEq./l. on the 4th postoperative day, in spite of definite sodium retention. This "sodium paradox" is the rule after trauma or major surgical procedures, and may be caused by a shift of sodium into the body cells or a movement of cell water into extracellular fluid, thus decreasing sodium concentration.

Case 2. A 39-year-old male was admitted to the Fort Miley Veterans Administration Hospital on Nov. 3, 1954. His symptoms included loss of libido and poten- tiala during the preceding year, frontal headaches which had been present for 4 months, and failing vision of 2 months’ duration.

Clinical examination disclosed bitemporal hemianopia; visual acuity was good. In roentgenograms of the skull, the sella turcica was enlarged. Tests to evaluate the level of endocrine function, listed in Fig. 2, revealed little evidence of hypopituitarism. The hypertonic saline test was normal. Bilateral carotid angiograms were considered normal.

On November 23, without hormonal supplements, a right frontal craniotomy was performed under general anesthesia, and a cystic chromophobe adenoma of the pituitary was removed.

During the postoperative period, polyuria and polydipsia were present for several days, but no other complications occurred. Radiation therapy was subsequently administered. The visual fields improved promptly and were normal when the patient was last examined in February 1955.

Metabolic Studies. The balance data, steroid excretion and blood eosinophils are charted in Fig. 2. Again, the pattern is similar in general to that occurring after any major surgical procedure. The large sodium intake on the 2nd postoperative day was caused by an unexpectedly high oral intake in addition to 155 mEq. of sodium administered intravenously. Sodium diuresis appeared on the following day, but a second period of positive sodium balance supervened on the 8th postoperative day. Steroid excretion was elevated immediately after operation, then gradually fell to normal levels within a week. The serum sodium concentration (in mEq./l.) was 135 on the 1st postoperative day, 140 on the 3rd day, 135 on the 6th day, 133 on the 10th day, and 139 on the 14th day after operation.

Case 3. A 32-year-old male was admitted to the Fort Miley Veterans Administration Hospital on Jan. 27, 1955. The patient had noted a gradual onset of unsteadiness of gait and change in speech 7 years before. During the 6 weeks immediately prior to admission, these symptoms had progressed more rapidly. In addition, vague headaches and slight dysphagia had begun shortly before entry.

Examination on admission disclosed mild truncal ataxia, left dysdiadokokinesis and mild ataxia on left finger-to-nose test. Speech was somewhat thickened, and the left plantar toe response was equivocal. No nystagmus was present.

On February 3, biparietal trephination and ventriculography were done under local anesthesia with 1 per cent procaine. Premedication consisted of 100 mg. of a barbiturate and 0.6 mg. of atropine. Sixty-five cc. of ventricular fluid were replaced with air, and subsequent roentgenograms were interpreted as demonstrating moderate generalized ventricular enlargement. There was no evidence of an intracranial tumor.

The patient withstood the procedure well. His temperature was 100° F. on the afternoon of the day of operation but remained normal thereafter.

Metabolic Studies. During the first 7 days following ventriculography, the pa-
Patient's only intake was a special formula, plus water as desired. Unfortunately, the exact figures of the daily amount of formula ingested were lost. However, except on the day of the procedure the patient consumed approximately two quarts of formula daily, containing about 60 mEq. of sodium and potassium and 12 gm. of nitrogen. Because the exact figures are not available, the electrolyte output only, not balance, has been charted in Fig. 3. These figures, together with the available intake data,

![Figure 3](image)

*Fig. 3. Case 3. From above downward: Sodium output, potassium output, serum sodium concentration, and fluid balance. The concentrations of blood eosinophils are listed on the right. Output data should be compared with daily intake of 60 mEq. (approximate) each of sodium and potassium (see text).*

indicate the development of two trends, i.e., relative oliguria and sodium retention. On the day of operation and the 1st and 2nd postoperative days, fluid intake was 5200 ml. and urinary output was 2100 ml. On the operative and first 3 postoperative days, the total urinary output of sodium was 40 mEq., while sodium intake was approximately 180 mEq. A moderate postoperative fall in blood eosinophils occurred. Negative nitrogen balance began on the 2nd postoperative day and a negative potassium balance on the 3rd. There was a slight fall in serum sodium concentration (143 mEq./l. to 138 mEq./l).

Five other patients who had craniotomies for intracranial tumors were studied from the standpoint of metabolic balance. The data are incomplete,
but from the information available, the metabolic response was qualitatively similar to that depicted in the foregoing cases.

**Postoperative Hyponatremia.** The next 2 patients were not studied by balance techniques, but are included because of the development of postoperative hyponatremia. The diagnosis in both instances was chromophobe adenoma of the pituitary.

**Case 4.** A 35-year-old female was admitted to the University of California Hospital on Oct. 20, 1954. Symptoms included amenorrhea (4 years), headaches (3 months), and impaired vision and diplopia (1 month). Bitemporal hemianopia was present, and loss of central vision had occurred on the right. Basal metabolic rate was plus 3 per cent, and protein-bound iodine was 4.9 μg./100 cc. (normal 4 to 8). The 24-hour urinary excretion of 17-ketosteroids, which was initially 2.5 mg., rose to 5.4 mg. following the administration of corticotrophin.

On Oct. 25, 1954, a right frontal craniotomy was performed under general anesthesia, and a large chromophobe adenoma of the pituitary was partially removed.

The patient was alert on the 1st postoperative day but became stuporous on the 2nd day. The craniotomy was re-explored, but no hematoma was found. On the 3rd day, a tracheotomy was done. The patient gradually improved and oral feedings were begun on the 6th postoperative day. Her temperature, which had risen to 40°C. (104°F.) on the 2nd postoperative day, was 37.5°C. (99.5°F.) on the 4th day. After removal of the tracheotomy tube, the patient was discharged on Nov. 10, 1954.

**Metabolic Studies.** Available data are charted in Fig. 4. It is evident that marked hyponatremia (116 mEq./l.) occurred on the 2nd postoperative day. Some degree of depression of adrenal function was probably present. However, on the 5th postoperative day, when the serum sodium concentration had risen to 141 mEq./l., the urinary sodium concentration was only 4 mEq./l., suggesting adequate renal conservation of sodium.

Dilution of the extracellular sodium, in addition to the usual postoperative fall in serum sodium concentration, probably contributed to the hyponatremia. On the day of operation and the 1st postoperative day, the patient received 4000 ml. of water, intravenously, but only 39 mEq. of sodium. The exact urinary output on the 1st postoperative day is not known, but it was small. For the 2 days, the urinary output was probably not more than 800 ml. Allowing for an insensible water loss of 600 to 850 ml. per day, the patient retained between 1.5 and 2 liters of water in this 2-day period, with less than 40 mEq. of sodium. As soon as the sodium intake was increased and the urinary volume increased, the serum sodium concentration rose and the patient improved rapidly.

Water intoxication has been observed in general surgical patients, sometimes in instances in which fluid intake has not seemed excessive. Dudley et al. believe that the mechanism of water intoxication is probably more complicated than simply hypotonicity of the extracellular fluid. Hypophysial and adrenal insufficiency increase susceptibility to water intoxication.

**Case 5.** A 48-year-old female had had a right frontal craniotomy and removal of a chromophobe adenoma of the pituitary in 1947. Four years later, diabetes mellitus was discovered and the patient was placed on 10 units of protamine zinc insulin daily. Three years after this, vision again began to fail.

When the patient was readmitted to the University of California Hospital, on
Jan. 23, 1955, the visual field of the right eye was reduced to a small island in the inferior nasal quadrant. There was loss of most of the temporal field of the left eye, but left visual acuity was good.

At re-operation on Jan. 31, 1955, a recurrent pituitary chromophobe adenoma was removed.

During the next 7 days, 3 to 4 plus glycosuria and slight acetonuria were present, despite administration of regular insulin. Acetonuria then ceased, and the urine was maintained sugar-free.

The patient's conscious state was satisfactory for 3 days after operation, following which she became restless and drowsy. The trend reached its maximum on the 5th and 6th postoperative days, when a deep stupor developed and the patient's temperature rose to 39.4°C. (102.9°F.). Spinal fluid pressure at that time was 560 mm. of water. During the 6th and 7th postoperative days, 500 ml. of 3 per cent saline were administered, and the patient began to rouse. On the 8th day, she was able to eat and 4 days later was discharged.

One month after discharge, the left visual field had improved, although the field of the right eye was unchanged. Twenty units of insulin per day were necessary to prevent glycosuria.

Metabolic Studies. The data in this case are shown in Fig. 5. Unfortunately, the
daily electrolyte intake and output were not determined except for the intravenous fluids listed at the bottom of Fig. 5. The cause of hyponatremia was more complex than in Case 4. Renal loss of sodium was probably appreciable, because of glycosuria and acetonuria.

Postoperative oliguria and positive water balance also occurred in this patient. These factors were particularly marked on the 4th postoperative day, when the intake was 3000 ml. and the urinary output was only 650 ml., resulting in a positive water balance of between 1500 and 1750 ml. (allowing for insensible loss). On the following day, when the patient was deeply stuporous, the serum sodium concentration was 120 mEq./l., and the serum potassium 5.7 mEq./l. The next morning, spinal fluid pressure was found to be markedly elevated. The administration of hypertonic saline resulted in fairly prompt response, and the patient was alert enough to eat on the 8th postoperative day. It should be noted that the serum sodium concentration barely rose on the 8th and 9th postoperative days (in spite of the high sodium intake), probably because of the strongly positive water balance on the previous day (intake 4540 ml., output 1550 ml.). The final serum sodium concentration was 130 mEq./l. on the day of discharge.

Fig. 5. Case 5. From above downward: body temperature range (°C.), serum potassium concentration, serum sodium concentration, fluid intake, urine output, estimate of degree of stupor and partial data of electrolyte intake. KCl indicates additional potassium chloride administered intravenously on February 4 and 5.
DISCUSSION

These studies delineate a metabolic response to craniotomy which is quite similar to that noted after other surgical procedures. The negative potassium and nitrogen balances and the positive sodium balance which occur initially are followed in several days by a reversal of these trends. In apparent direct contradiction to the net balance, the serum sodium concentration tends to fall initially, and the serum potassium to rise. Case 3 is of particular interest in that a procedure under local anesthesia involving minimal surgical trauma induced a fairly strong response, especially in regard to sodium retention and oliguria. Perhaps irritation of the ventricular walls by air stimulated the hypothalamus, which in turn activated the anterior and posterior lobes of the pituitary.\(^{15}\)

Cases 4 and 5 illustrate the development of hyponatremia following craniotomy. Because of the impaired state of consciousness, both patients were suspected of having intracranial hematomas, and in one, re-exploration was carried out. The rapid improvement following administration of hypertonic saline was striking, and no hormonal supplements were necessary.

Postoperative oliguria appears to have played an important role in the development of the hyponatremia. The oliguria, which has been noted after other surgical procedures,\(^{19,20}\) tends to vary with the severity of the operation and is not affected by replacement of operative blood loss or a large intake of fluid.\(^{7}\) It does not depend on sodium retention, but is presumed to be caused by release of antidiuretic hormone.\(^{10,18}\) Case 3, in which there was only minimal trauma to tissues and no general anesthetic would tend to support the theory that oliguria is of posterior pituitary origin.

Data presented in two recent studies of patients who had mitral valvulotomy are pertinent to this problem. Wilson et al.\(^{24}\) allowed 60 patients unlimited fluid intake in the immediate postoperative period, while 30 patients were restricted to 1500 ml. per day. The two groups allowed unrestricted fluids drank 3210 ml. and 3460 ml. more in a 3-day period, but excreted only 850 ml. and 810 ml. more urine, respectively, than the group whose fluids were restricted. Associated with this fluid retention, there was a greater fall in serum sodium concentration than in the fluid-restricted group. In explaining the postoperative fall in serum sodium concentration, however, the authors stated that "'external dilution' is not the only significant factor, if it is assumed that the retained water is evenly distributed over the body."\(^{24}\) Some workers have suggested that this retained water remains largely in the extracellular space.\(^{19,20}\)

Bruce et al.\(^{5}\) divided their patients into three groups. Twelve patients (Group I) were allowed unrestricted fluids postoperatively but no saline. Eighteen patients (Group II) were given unrestricted fluids plus some saline (average 61 mEq. of sodium per day). Ten patients (Group III) were allowed less than 1 liter of water per day and no saline. The incidence of hyponatremia (serum sodium below 127 mEq./l., in this instance) was 33 per cent
in Group I, 39 per cent in Group II, and 10 per cent in Group III. The average for each group showed a greater fall in serum sodium in Groups I and II than in Group III. In 2 patients in Group I (unrestricted fluids) there developed marked hyponatremia, associated with stupor and delirium. They improved promptly when saline was administered.

These two studies suggest that retention of water (without sodium) plays a role in the usual postoperative fall in serum sodium concentration, by diluting the sodium present. Dudley et al.10 found that retention of water in the postoperative period resulted in a decrease of serum sodium concentration greater than that calculated from simple dilution (assuming the retained water is equilibrated with total body water). Other suggested mechanisms include intracellular shift of sodium23,34 or "internal dilution" by cell water.34

In determining the type of intravenous fluids to be given during and after craniotomy, the metabolic response to the operative procedure must be considered. It has been suggested that intravenous solutions of 2.5 per cent glucose in 0.42 per cent sodium chloride3 or sodium lactate33 be used during and following craniotomy to avoid the brain swelling which may be caused by electrolyte-free fluids. In patients who have had craniotomy on the Neurosurgical Service at the University of California Hospital, 0.45 per cent saline has been used in selected cases for several years without any apparent adverse effects. However, the postoperative sodium retention may be dangerous in patients with cardiac disease. Two of the patients reported by Bruce et al.5 were allowed unlimited fluids and some saline (about 60 mEq. per day) following mitral valvulotomy. After intravenous administration of sodium lactate, both patients died of acute pulmonary edema.

Restriction of fluid intake during the operative and postoperative period may minimize postoperative hyponatremia with its attendant risk of cerebral edema. This was suggested in the treatment of head trauma some years ago by Fay.11 However, the severe restriction of fluid intake (600 cc. per day) which he advocated may result in dehydration.

Dehydration is not advocated, but rather careful avoidance of overhydration. Wilson et al.34 demonstrated that increasing the postoperative fluid intake does not result in a commensurate increase in urine output, but in fluid retention. Their restricted fluid intake was 1500 ml. per day, while Bruce et al.5 allowed less than 1 liter per day. Studies in patients without cardiac disease supported these conclusions.7,10,15,35 However, severe restriction in fluid intake may be associated with some increased danger of venous thrombosis.

No single arbitrary figure for fluid intake can be proposed because of variables, such as climate, body weight and body temperature, which affect fluid loss. If sodium-containing fluids are administered, the amount is less critical, except insofar as total body water and cardiac status are concerned. If electrolyte-free fluids are used, the volume must be calculated according to output of urine, presumed insensible loss, and extrarenal loss. Oliguria may occur and persist for several days after craniotomy. A daily urinary
volume of 500 to 700 ml. is thought to be adequate during the first 2 days following a major surgical procedure. An attempt to maintain an arbitrary higher urinary volume during this time by forcing fluids may result in marked fluid retention.

The simplest indicator of fluid retention is the daily weight of the patient. A patient should lose weight after an operation.  Postoperative increase in weight is "an outstanding abnormality of surgical metabolism," and generally indicates retention of fluid.

**SUMMARY**

Studies of the metabolic response to craniotomy are reported. The data obtained indicate that the metabolic alterations are similar to those noted after other surgical procedures and include sodium retention, potassium loss, nitrogen loss, and frequently oliguria. These trends are reversed in several days.

Two patients in whom hyponatremia developed following craniotomy for pituitary tumors are described. Fluid retention without sodium administration appeared to be partially responsible for the hyponatremia. The patients were comatose when the serum sodium concentration was low and regained consciousness shortly after the administration of hypertonic saline.

The type and amount of intravenous fluid to be administered during and following craniotomy are discussed in the light of these studies.

The laboratory studies in Cases 2 and 3 were done under the direction of Dr. T. V. Feichtmeir, Chief of the Clinical Laboratory at Fort Miley Veterans Administration Hospital. In the remaining cases, the studies were done in the Central Laboratory of the University of California Hospital (Dr. W. L. Bostick, Director). Miss Kay Hyde drew the charts. The author is also indebted to Dr. E. B. Boldrey and Dr. I. S. Edelman for valuable advice and criticism, and to Mrs. M. Beaglher for editorial assistance.

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