Management of Electrolyte and Fluid Disorders after Brain Surgery for Pituitary/Suprasellar Tumours

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Key Words

Diabetes insipidus · Cerebral salt wasting · Syndrome of inappropriate antidiuretic hormone secretion · Neurosurgery

Abstract

Disturbances in salt and water balances are relatively common in children after brain surgeries for suprasellar and pituitary tumours, presenting diagnostic and therapeutic challenges. Although hypernatraemia associated with central diabetes insipidus is commonly encountered, it is hyponatraemia (HN) that poses more of a diagnostic dilemma. The main differential diagnoses causing HN are the syndrome of inappropriate antidiuretic hormone secretion, marked by inappropriate retention of water, and cerebral salt wasting, characterized by polyuria and natriuresis. Diagnosis and management can be even more difficult when these conditions precede or coexist with each other. These diagnostic and therapeutic dilemmas are discussed in detail in this review.

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Introduction

Due to the anatomic location of suprasellar and pituitary tumours, interventional brain surgery can have peri- and postoperative complications related to anterior and

posterior pituitary dysfunctions with fluid and electrolyte disorders. Conditions such as central diabetes insipidus (CDI), which can be transient or permanent, partial or complete, the syndrome of inappropriate antidiuretic hormone secretion (SIADH), cerebral salt wasting (CSW) and dipsic diabetes insipidus (ADI) can occur/coexist, making clinical management extremely challenging. Anterior and posterior pituitary dysfunction can also be present at diagnosis.

The aim of this article is to review the pre- and postoperative management of electrolyte and fluid disorders after brain surgery for pituitary/suprasellar tumours and to discuss the diagnostic and therapeutic challenges encountered based on the authors' personal experience, as well as a review of the relevant literature and published guidelines.

Definitions

CDI is characterized by the excretion of large volumes of dilute urine (polyuria) due to vasopressin (ADH) deficiency. Polyuria is characterised by a urine volume in excess of 2 l/m²/24 h or approximately 150 ml/kg/24 h at birth, 100–110 ml/kg/24 h until the age of 2 years and then 40–50 ml/kg/24 h in an older child or adult. The criteria for the diagnosis of CDI in the postoperative setting are represented in table 1.

SIADH is defined by hyponatraemia (HN) and hypo-osmolality due to inappropriate ADH secretion which re-

Table 1. Criteria for the diagnosis of diabetes insipidus in the post-operative period

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- (1) Increased plasma osmolality >300 mosm/kg
 - (2) Increased urine output >2.5 ml/kg/h for 2 consecutive hours
 - (3) Urine osmolality <200 mosm/kg
 - (4) Urine/plasma osmolality ratio <1
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sults in impaired water excretion despite a normal or increased plasma volume.

CSW is defined by the development of extracellular volume depletion due to a renal sodium transport abnormality in patients with intracranial disease and appropriate adrenal and thyroid status.

Pre-Operative Overview

In children, craniopharyngioma is the commonest tumour involving the mentioned anatomic areas. Other tumours are functioning and non-functioning pituitary adenomas, germinomas and non-germinomatous germ cell tumours, Langerhans cell histiocytoses, chiasmatic (low-grade) gliomas, suprasellar arachnoid cysts and hypothalamic-pituitary astrocytomas [1]. These tumours present with acute or more insidious compression symptoms of adjacent neural structures leading to a raised intracranial pressure with hydrocephalus in 50%, visual impairment in 38% and endocrine abnormalities in 66–77% of cases [1, 2], with a higher incidence in craniopharyngiomas than in the other tumour types [2–5]. Although symptoms due to neuroendocrine dysfunction may not be obvious at presentation [6], clinical features of endocrinopathies are frequently found on careful assessment and have often been present for months or years prior to presentation. Establishing the endocrine status of the patient before surgery is essential in managing peri-operative complications.

Growth hormone deficiency is one of the commonest endocrine abnormalities, being present in 50% of children with suprasellar and pituitary tumours at diagnosis [1]. This is higher in children with craniopharyngiomas where an incidence of 72–95% can be found on provocative testing [4–10]. Growth deceleration is one of the commonest findings in children but is often recognized only retrospectively, as presentation with growth failure is less common [3]. As the need for urgent surgical intervention for raised intracranial pressure takes priority at diagnosis, there is less opportunity to make a diagnosis of

growth hormone deficiency via provocative testing, in which case the measurement of a baseline insulin-like growth factor-1 level can be helpful. If the patient is receiving growth hormone therapy, this should be stopped prior to surgery, as is recommended in any patient with an acute critical illness [11].

Hypoadrenalism associated with suprasellar tumours can be secondary or tertiary. This hypoadrenalism is potentially lethal if not recognized and managed appropriately. It has been reported pre-operatively in 50% of patients with pituitary and suprasellar tumours [1] and in about 25–71% of patients with craniopharyngiomas on provocative testing (short synacthen or insulin tolerance test) [4–10]. An appropriately raised early morning cortisol (for instance >500 nmol/l in patients not severely unwell [12]) makes the diagnosis unlikely. Hypocortisolism may cause HN through an increase in ADH levels and by impaired free water excretion [13]. Cortisol replacement should be initiated if patients are found to be cortisol deficient pre-operatively. Stress doses of corticosteroids should be used be prescribed to cover neurosurgery in these patients as well as in patients with a normal adrenal axis. If the patient is receiving treatment with dexamethasone for a neurosurgical indication, no additional corticosteroid cover for surgery is required, but postoperative cortisol replacement should be initiated once dexamethasone is weaned and continued until there is a formal assessment of the hypothalamic-pituitary-adrenal axis.

CDI is found in 12% of patients with pituitary and suprasellar brain tumours at presentation [1]. In a recent review of children with craniopharyngiomas, 17–27% have been reported to have diabetes insipidus [14]. CDI is also the most frequent central nervous system manifestation of Langerhans cell histiocytosis, occurring in 10–50% of all patients [15, 16], while in intracranial germ cell tumours CDI occurs in 82% of cases [17]. Polyuria and polydipsia are the presenting symptoms but may not be obvious in mild forms of CDI. If CDI coexists with untreated adrenal insufficiency, polyuria and polydipsia can be masked due to the free water retention caused by the adrenocortical failure. These symptoms may become apparent on direct questioning, documentation of a 24-h fluid balance or following the initiation of a pharmacological steroid treatment. In patients with CDI, a normal sense of thirst with free access to fluid intake will allow normal plasma electrolytes and osmolality. If, however, patients are unable to compensate for urinary losses, for example due to unconsciousness, vomiting or restricted fluid access, they will develop increased plasma osmolal-

Table 2. Pre-operative endocrine assessment and investigations

- (1) Careful medical history, previous growth pattern and physical examination
- (2) Current height, weight, surface area, pubertal staging and bone age
- (3) Accurate fluid intake and output record
- (4) Paired early morning plasma and urine osmolalities
- (5) Serum urea, creatinine, electrolytes and glucose
- (6) Thyroid function (thyroxine and thyrotropin)
- (7) Cortisol at 9 a.m. (if patient is not receiving steroids)
- (8) Prolactin (to exclude prolactinoma)
- (9) α -Fetoprotein and β -hCG (to exclude secreting germinoma)
- (10) Insulin-like growth factor-1

ity (>300 mosm/l) with decreased urine osmolality and a urine/plasma osmolality ratio <1 . In the peri-operative period, formal water deprivation testing is not needed as it may not provide any more information towards the diagnosis of CDI in children with a known pituitary hypothalamic endocrine tumour. If time allows, a patient with newly diagnosed pre-operative CDI should be treated and stabilized before surgery by the use of desmopressin (DP), which is a synthetic analogue of ADH, otherwise fluid losses should be appropriately replaced.

SIADH has occasionally been described before surgery, presenting with HN and seizures responding to fluid restriction [18, 19]. The tumour mass might cause inappropriate ADH release by direct mechanical stimulation and/or ischaemic changes on the osmoreceptor/ADH-secreting neurons.

Secondary/tertiary hypothyroidism has been described in 2.7–42% of patients with craniopharyngiomas pre-operatively [4–6, 8–10]. Central hypothyroidism presents with an inappropriately low thyrotropin level in a setting of low thyroxine or free thyroxine levels. It should be treated with thyroxine replacement before surgery. In moderate to severe hypothyroidism, HN can occur due to reduced cardiac output which can lead to the release of ADH via the carotid sinus baroreceptors and decreased glomerular filtration with reduced free water excretion [20]. In naïve patients with both thyrotropin and adrenocorticotropin deficiencies, hydrocortisone replacement should precede the replacement of thyroxine as the latter increases the metabolic clearance of glucocorticoids and may lead to adrenal crisis if the initiation of thyroxine precedes that of hydrocortisone.

Whenever possible, pre-operative endocrine assessment and investigations (table 2) should be performed.

Postoperative Overview

Surgery in the hypothalamic-pituitary area is often accompanied by disturbances of water, electrolytes and osmoregulation due to manipulation and vascular alteration of the neurohypophysis. Abnormalities in blood osmolality can be life-threatening if they are not properly recognized and treated. Fluid intake and output should be recorded very accurately and reviewed every 6–8 h. Insertion of a urinary catheter may be necessary for an accurate output record. Extra fluid losses like stools, cerebrospinal fluid or drain outputs should be accounted for and replaced. Paired plasma and urine osmolality and electrolytes should be tested immediately postoperatively and every 8 h, but changes in plasma sodium of >5 mmol/l will require more frequent testing (every 4 to 6 hours) [21].

CDI is a common postoperative complication that occurs in 83% of patients with intrasellar and parasellar tumours [2], especially in those with large tumours damaging the ADH-secreting neurons and radical surgical excision with pituitary stalk resection. Other factors found to be associated with an increased risk of developing postoperative CDI are a young age, male gender, CSF leak, and resection of certain types of lesions including craniopharyngiomas, Rathke's cleft cysts and ACTH-secreting pituitary adenomas [22–24].

Over the last decade, the surgical approach towards craniopharyngiomas has been changing. Previously, gross resection of the tumour was the treatment of choice. In recent years, newer conservative surgical treatments like endoscopic transsphenoidal surgery and cyst decompression with or without intracystic treatment have been introduced to reduce morbidities. This has led to less postoperative endocrine complications like permanent CDI, now seen in 50–55% of patients after conservative surgery combined with radiation surgery [14], as compared to 60–90% of patients with aggressive surgery.

The course of postoperative CDI can be transient, permanent or triphasic. The triphasic pattern (fig. 1) occurs in 3.4% of patients who undergo transsphenoid surgery, and only the first 2 phases occur in 1.1% of patients [22]. In the triphasic pattern, the initial phase of CDI is followed by a second oliguric phase of SIADH and then by a third and final phase of permanent CDI [25, 26].

Transient CDI becomes evident within 24–48 h of surgery (fig. 1a). The hypotonic polyuria lasts for 5–7 days. This initial phase of the triphasic pattern and transient CDI are both thought to be caused by a temporary dysfunction of ADH-producing neurons either second-

Fig. 1. Mechanisms that underlie the pathophysiology of the triphasic pattern of postoperative diabetes insipidus. Phase a: the first phase diabetes insipidus is initiated by a partial or complete pituitary stalk section, which damages the connection between the cell bodies of ADH-secreting neurons in the hypothalamus and their nerve terminals in the posterior pituitary gland, which prevents ADH secretion. Phase b: the first phase is followed, after several days, by the second phase of SIADH, which is caused by an uncontrolled release of ADH into the blood stream from the degenerating nerve terminals in the posterior pituitary. Phase c: after all of the ADH stored in the posterior pituitary gland has been released, a third phase of diabetes insipidus develops if more than 80–90% of ADH-secreting neuronal cell bodies in the hypothalamus have degenerated. Figure 1 has been adapted with permission from the author [26] and publisher.

ary to oedema due to trauma to the connections between the magnocellular cell bodies and the nerve terminals in the posterior pituitary or to axonal shock from perturbations in the vascular supply to the pituitary stalk and posterior pituitary. Transient CDI usually resolves when ADH-secreting neurons recover their normal function [26].

The second phase of SIADH is caused by an uncontrolled release of ADH from either degenerating posterior pituitary tissue or from the remaining magnocellular neurons whose axons have been damaged (fig. 1b). In this phase, urine output decreases and urine becomes concentrated. The duration and severity of this phase is variable and may last from 2 to 14 days [26]. Severe and long-lasting HN due to SIADH can be a predictor for a future occurrence of permanent CDI, as both conditions are due to damage to the ADH-secreting neuronal cell bodies in the hypothalamus.

Partial or limited damage to some axons connected to the posterior pituitary may be associated with isolated second phase SIADH due to the uncontrolled release of accumulated ADH resulting in transient asymptomatic or symptomatic HN [27].

The third phase of permanent CDI, in which polyuria reappears within 2 weeks, follows depletion of ADH due to the degeneration of hypothalamic ADH-secreting neuronal cell bodies (fig. 1c). A major determinant of whether CDI following transection of the pituitary stalk is permanent or not is related to how close the level of the lesion is to the ADH-secreting neurons' cell bodies in the hypothalamus [28].

Figure 2 illustrates the changes in the urine output and plasma sodium concentrations with the main therapeutic interventions during the first 14 postoperative days in a 10-year-old child with craniopharyngioma who developed the triphasic response.

In addition, the patients may develop CSW, which can develop as a primary (neuronal insult) or as a secondary response to SIADH. In CSW, there is a defect in the renal sodium transport which leads to extracellular volume depletion and HN.

Thirst abnormalities, such as adipsia or hypodipsia due to osmoreceptor damage, can lead to hypernatraemia and wide fluctuations in osmolality complicating the management of the water and electrolyte balance, as they usually coexist with CDI and ACTH deficiency.

Fig. 2. Triphasic response. This represents the daily urine output (measured as ml/kg/h) and the plasma sodium concentration in the first 14 postoperative days in a 10-year-old child with cranio-pharyngioma who developed a triphasic response. The main therapeutic interventions are represented at the bottom of the graph.

In the initial phase of transient diabetes insipidus, DP was used on an 'as-required basis' to reduce the urine output. In the second phase of the SIADH, fluid access was restricted. When the third phase with permanent diabetes insipidus developed, DP was restarted and given on a regular basis.

Central Diabetes Insipidus

While CDI can present within a few hours after surgery, abnormalities of ADH secretion and fluid balance often begin during the intra-operative period. The diagnosis of CDI should be made with caution as intra-operative fluid overload also presents with hypo-osmolar polyuria. It is also important to rule out glycosuria and hyperglycaemia, especially if the patient is on dexamethasone. Diagnosis of CDI is made on the basis of clinical and biochemical findings. The patient may develop a sudden onset of polyuria (urine output >2.5 ml/kg/h) and polydipsia, usually within the first 24–48 h after neurosurgery. Plasma osmolality is increased (>300 mosm/l), and urine osmolality is decreased with a urine/plasma osmolality ratio <1 . The urine specific gravity (USG) can also be used at the bedside to guide diabetes insipidus management if there is a delay in obtaining urine osmolality results from the laboratory. USG determined by both reagent strip and refractometry has a correlation of approximately 0.75 with urine osmolality [29]. This relationship between the specific gravity and osmolality is disturbed when the urine contains an abnormal solute, such as glucose or protein. USG is also affected by temperature, with urine density decreasing (lower USG) with increasing temperature.

It is important to assess whether the thirst mechanism is preserved postoperatively. Patients often have a craving for ice-cold water and increased thirst if the thirst mechanism is intact. Patients with CDI having intact thirst mechanisms and free access to oral fluids may not devel-

op hypernatraemia and hyperosmolality. However, if they are unable to drink enough to maintain normal plasma osmolality and serum sodium levels, or they are adipsic, they need to be encouraged to drink and should be offered drinks regularly. If fluids need to be supplemented, then two thirds of the fluid maintenance can be replaced with 0.9% saline. Fluid losses in excess of the maintenance fluid rates minus insensible losses (300 ml/body surface area in m^2) should be replaced volume for volume by calculating and matching the fluid balance at least 6 hourly [21]. Fluids can be replaced by water given orally or via a nasogastric tube or by 0.45% saline intravenously in eunatraemic patients. Non-urinary fluid losses should be replaced with 0.9% saline. As long as fluids are replaced, CDI is not life-threatening. DP can be started to reduce the total daily fluid intake/output. It can be given at an initial dose of 50–100 μ g (tablets) orally, 5–10 μ g intranasally or 30–60 μ g sublingually. Each subsequent dose of DP should be given after the demonstration of dilute urine with an osmolality <200 mosm/l or a specific gravity <1.005 , and a urine output of >2.5 ml/kg/h for >2 h. Treatment results in the reduction of urine output, with the effect lasting for 6–18 h, and doses should be titrated according to the daily total urine output. To minimize the risk of water intoxication and HN in resolving transient CDI, DP should be given on an 'as-required basis' until it is established that the CDI is permanent. If the route of administration needs to be changed for any other reason, the dosages of the different forms of DP are not directly interchangeable.

In a paediatric intensive care setting, low dose DP (0.1–0.2 µg s.c./i.m) [30] or dilute arginine ADH (0.25–3 mU/kg/h) by a continuous intravenous infusion [28, 31, 32] is often used in the first 24–48 h postoperatively. Arginine ADH has a short half-life (10–20 min), and its therapeutic effects dissipate quickly once the infusion is stopped. Intravenous arginine ADH infusion also increases blood pressure. The continuous infusion needs close monitoring of the fluid balance and electrolytes and frequent titration of the infusion rate to achieve the desired fluid output. Prolonged use of arginine ADH may result in antibody formation and in a shortened duration of action of the drug [33].

Regular DP should only be prescribed when CDI is stable and permanent. The aim of the treatment is to ameliorate polyuria and polydipsia, not to entirely normalise daily fluid intake. Once a day, breakthrough polyuria before dosing should be encouraged to avoid water intoxication. If HN occurs during DP therapy, the DP dose should be withheld until the sodium level normalises. If DP is continued or if excreted free water is continued to be replaced, this can lead to cerebral oedema.

Syndrome of Inappropriate Antidiuretic Hormone Secretion

SIADH can occur in the postoperative period due to damage to neurons with release of intracellular ADH [34]. In the postoperative period, transient SIADH can be isolated or can occur after an initial phase of transient CDI. Isolated SIADH occurs in patients with limited damage to the neurohypophysis. It occurs in 8–21% of patients after pituitary surgery [22, 35].

SIADH is clinically characterized by a significantly reduced urine output in the presence of euvolaemia and hypervolaemia, and patients often report increased thirst. Biochemically, SIADH is characterized by low plasma osmolality (<270 mosm/kg) with inappropriately high urine osmolality (>100 mosm/kg), HN with urine sodium loss >20 mmol/l, suppressed plasma renin activity, low haematocrit, low plasma urea and uric acid [36, 37].

The therapeutic intervention for SIADH is fluid restriction [34, 36, 38]. Intravenous fluids should be stopped in the postoperative period in all patients as soon as they are able to drink. This is to prevent the development of severe HN in case SIADH develops and the intravenous fluid rate is not adjusted accordingly. In severe cases, only insensible losses (300 ml/body surface area in m²) need to be replaced. If a patient is enterally fed, insensible losses can be covered by food intake. Sodium replacement is required only in prolonged SIADH caus-

ing total body sodium depletion. Symptomatic severe HN with signs and symptoms of cerebral oedema, which include visual changes, focal neurologic changes, encephalopathy, respiratory depression and seizures, needs to be treated with an infusion of 3% saline at 0.5–1 mmol/kg/h (1–2 ml/kg/h) for 2–3 h, followed by conservative adjustments [37, 39, 40]. This is a temporary measure to increase sodium to a safer level. Overcorrection should be avoided by limiting the rate of correction to <10–12 mmol/l during the first 24 h of treatment and to <18 mmol/l over 48 h. A rapid rate of the correction of HN can lead to a serious and permanent neurological manifestation, central pontine myelinolysis and death [39, 41].

Cerebral Salt Wasting

CSW is reported in 4% of children following neurosurgery and is characterized by polyuria and natriuresis [42]. CSW is a process of extracellular volume depletion due to a tubular defect in the sodium transport. The precise underlying pathophysiology is unclear, but it has been postulated that the presence of natriuretic peptides (NP) released from the injured brain and the loss of sympathetic stimulation to the kidney can lead to CSW [43].

Several NP have been identified and described with CSW, and the best known are atrial NP and brain NP. These are small polypeptides which cause natriuresis, diuresis, vasodilation, and suppression of renin, aldosterone and ADH secretion. Inappropriate NP secretion may be a pathogenic mechanism for CSW [43]. An overview of the NP theory and physiopathology can be found in the publication by Yee et al. [44].

Sympathetic inhibition normally causes proximal tubule absorption of sodium. Depression of this sympathetic input to the kidney results in less sodium reabsorption in the proximal tubule and in an increase in sodium delivery to the distal tubule. This leads to a decrease in the effective arterial blood volume, triggering the baroreceptors to release ADH to help maintain the intravascular volume. A depressed sympathetic drive has also been associated with a decrease in renin and aldosterone levels, further inhibiting sodium retention [43, 44].

CSW and SIADH can both present with HN in patients with brain injuries such as head trauma, intracranial tumours, infectious meningitis, subarachnoid haemorrhages and in postoperative neurosurgical cases. Making the distinction between CSW and SIADH is important, as the treatment for the 2 conditions is very different. Water and salt supplementation is the primary therapy for CSW, whereas fluid restriction is required for SIADH.

Table 3. Clinical and biochemical differences between SIADH and CSW

	SIADH	CSW
Body weight	increased	same or decreased
Plasma volume	high	low
Evidence of volume depletion	no	yes
Central venous pressure	same or increased	decreased
Plasma sodium	low	low
Urine sodium	high	high
Net sodium loss	normal	high
Urine output	usually low	very high
Plasma osmolality	low	low
Urine osmolality	high	high
Urine/plasma osmolality ratio	>1	>1
Plasma urea	low	normal/high
Serum uric acid	low	normal
Haematocrit	low	normal/high
Plasma renin	suppressed	normal/high/suppressed
Plasma aldosterone	normal/high	suppressed
Plasma ADH	high	suppressed
Plasma NP	high	high

CSW and SIADH both present with similar laboratory findings in acute clinical circumstances: low serum osmolality and inappropriately high urine osmolality. There is significant natriuresis (urinary sodium losses >40 mmol/l) in both conditions. While the urinary sodium excretion [urinary sodium concentration (mmol/l) $\times$ urinary volume (l/24 h)] is substantially higher than the sodium intake in the CSW syndrome, it generally equals the sodium intake in SIADH. Therefore, the net sodium balance (intake minus output) is negative in CSW with polyuria, while in SIADH there is a euvolemic or mild extracellular fluid expansion. The clinical history of polyuria or oliguria and clinical signs of hypovolaemia, such as hypotension, tachycardia and poor skin turgor, are useful in differentiating the 2 conditions [43, 44]. Sometimes, in milder cases of hypovolaemia and euvolaemia, it is challenging to distinguish CSW from SIADH. Table 3 summarizes the main clinical and biochemical differences between the 2 conditions. In an intensive care setting, where patients receive different types of intravenous fluids, calculating the net sodium and water balance as well as the fractional excretion of the sodium/free water clearance can be helpful in understanding water and electrolyte imbalances.

Early appropriate fluid therapy and salt supplementation should be initiated to prevent further complications.

Depending on the severity and clinical symptoms of HN, isotonic or hypertonic fluids are given to correct volume depletion. Sodium can be supplemented by the oral route. CSW may need an aggressive replacement of fluids in the paediatric intensive care unit, with central venous pressure monitoring. A strict fluid regime of 'millilitre for millilitre' replacement should be avoided as a vicious cycle of replacing fluids might result in polyuria. Although water and salt supplementation is the primary therapy, mineralocorticoid administration (fludrocortisone) has been used for the treatment of CSW at doses of 0.025–1 mg/day [43, 45, 46]. The commonest adverse effects of fludrocortisone are hypokalaemia, which was observed in 73% of patients [43, 47], and hypertension [46, 47].

Once the underlying cause of CSW is corrected, CSW is usually a transient condition that resolves within 3–4 weeks. Occasionally, it can be long-standing and can last for months [48–50]. If the duration of CSW is prolonged, conditions such as CNS infection, CSF obstruction and tumour progression should be carefully checked for. If these conditions are present, they can sustain CSW.

Coexisting CDI and CSW

In patients where CDI and CSW coexist, sodium loss due to CSW in itself contributes to the polyuria. This polyuria should not be considered as a sign of poorly controlled CDI [50]. Higher DP doses should be avoided as this increases renal free water reabsorption and aggravates HN. Treatment consists of sodium and fluid replacement, titrated against losses, and cautious continuation of DP, with close monitoring of plasma electrolytes and osmolality. Central venous pressure monitoring may be needed to guide fluid replacement in deteriorating patients.

Hypothalamic ADI

This is a rare, but challenging condition characterised by hypotonic polyuria due to ADH deficiency and failure to generate the sensation of thirst in response to hypernatraemia and increased plasma osmolality [51]. The sites of lesion are the osmoreceptor cells in the circumventricular organ of the anterior hypothalamus. Patients with this condition fail to drink fluids due to the lacking thirst mechanism, resulting in dehydration with hypernatraemia. They are also at risk of HN if they have coexisting CDI and excessive fluid is given while they are on DP. Both hypernatraemia and HN result in similar clinical symptoms such as lethargy, weakness, irritability, nausea, vomiting, seizures, coma and even death. The management of the fluid balance in patients with hypothalamic ADI is therefore very challenging.

Postoperative ADI and thirst abnormalities have been reported in about one third of patients with craniopharyngiomas using the hypertonic saline infusion test [52, 53]. Surviving patients with ADI have been found to regain their thirst sensation within 1 year after surgery, but the likelihood of recovery beyond that is small [54]. Thirst recovery can be assessed by the ADH and thirst responses to graded hyperosmolar stress [54].

The most practical approach to the management of ADI is to set an obligate urine output with a fixed amount of DP and to have a flexible amount of water intake to maintain euvolaemia and normal osmolality. This involves daily weighing, monitoring of urine output and frequent measuring of plasma sodium and osmolality. A detailed protocol for this management can be found in the publication by Ball et al. [51].

ADI is linked with increased mortality and morbidity due to associated complications including seizure, obstructive sleep apnoea and obesity-related hypoventilation syndrome. Measures should be taken to identify these complications [55]. Venous thrombosis has been reported

as a complication of plasma volume contraction and plasma viscosity, and recommendations have been made for the routine prescription of prophylactic subcutaneous heparin during hypernatraemic dehydration [55, 56].

Conclusions

In summary, the management of postoperative fluid and electrolyte disorders after brain surgery is challenging. These patients should be referred to specialist centres and managed by designated multidisciplinary teams involving a neuroradiologist, paediatric neurosurgeon, paediatric oncologist and paediatric endocrinologist with access to appropriate specialist pathology and paediatric intensive care facilities.

Disclosure Statement

The authors have no conflicts of interest to declare.

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