Central neurogenic diabetes insipidus, syndrome of inappropriate secretion of antidiuretic hormone, and cerebral salt-wasting syndrome are secondary events that affect patients with traumatic brain injury. All 3 syndromes affect both sodium and water balance; however, they have differences in pathophysiology, diagnosis, and treatment. Differentiating between hyponatremia (central neurogenic diabetes insipidus) and the 2 hyponatremia syndromes (syndrome of inappropriate secretion of antidiuretic hormone, and cerebral salt-wasting syndrome) is critical for preventing worsening neurological outcomes in patients with head injuries. (Critical Care Nurse. 2012;32[2]:e1-e8)

Traumatic brain injury (TBI) in adults continues to be a major cause of death and disability in the United States. An estimated 1.7 million persons in the United States will sustain TBI; of these, approximately 52,000 will die of the injury, 275,000 will be hospitalized, and 1.4 million will be treated and released from an emergency department. Although young children (0-4 years old) and adolescents (15-19 years old) have the highest risk of TBI, older adults (≥75 years) have the highest rates of TBI-related hospitalization and death. Patients who survive the initial injury are likely to have secondary complications that can result in permanent disability. Approximately 80,000 to 90,000 patients experience long-term disability each year because of TBI.

The most common causes of TBI are falls (35.2%), motor vehicle accidents (17.3%), being struck by or against objects (16.5%), assaults (10%), and sports-related injuries and penetrating trauma (21%). Although as many as 10% of TBIs result in death due to the primary injury, in most patients, marked morbidity and mortality are due to the effects of secondary injury. Primary injury is the damage caused by the initial trauma. Secondary injury, which occurs seconds, minutes, hours, or even days after the
initial trauma, is the result of biochemical processes that occur at the cellular level when neurons are damaged. Hypotension, hypoxia, cerebral edema, and electrolyte imbalance further worsen neurological outcomes and markedly affect morbidity and mortality. In this article, we discuss how electrolyte imbalances caused by injury of the pituitary gland complicate the recovery of patients with TBI.

Pathophysiology of TBI

Primary TBI is caused by 2 main mechanisms: direct impact (ie, an object strikes the head or the brain) and acceleration-deceleration injury (ie, the force of the impact causes the brain to ricochet inside skull, resulting in shearing of cerebral axons). Direct impact caused by blunt trauma, falls, or penetrating injuries can result in cerebral edema and intracranial hemorrhage, which can lead to severe deterioration in a patient’s clinical condition and even death.

Acceleration-deceleration injuries often cause diffuse axonal injury. The rotational shearing of gray and white brain matter results in microscopic damage of the axons of the brain. Initially, diffuse axonal injury usually is not visible on imaging studies; however, because of axonal degeneration, abnormal findings such as edema, atrophy, and petechial hemorrhages eventually are visible on magnetic resonance images. Acceleration-deceleration forces can also cause injuries of the cranial nerves, the hypothalamus, and the pituitary stalk. The damage that occurs with the primary injury is soon overtaken by the secondary injury from the cerebral edema, hemorrhage, or the hypoxia caused by a chain of ischemic events at the cellular level.

Ischemic Cascade of Neuronal Cell Death

Secondary injury of the brain is the damage that occurs seconds, minutes, hours, or even days after the traumatic event and may even be superimposed on a mechanical injury. Because of the primary injury, oxygen and nutrients are not delivered to brain cells. Hypoxia due to decreased cerebral blood flow results in biochemical processes involving a cascade of ischemic events. This hypoxia causes dysfunction in normal cellular metabolism, and neurons die. The sequence of events begins with a lack of oxygen and cerebral perfusion, which causes the cellular ion pumps to fail, leading to anaerobic metabolism and buildup of lactic acid. Active transport of cellular ions becomes impaired, and calcium ions flow into the neurons. Excitatory neurochemical transmitter substances such as glutamate are released, allowing even more calcium into the cells. This excess calcium causes release of oxygen free radicals and excess enzymes. The cell membrane is damaged by these enzymes, the mitochondria break down, and cellular death occurs. When cells die, more glutamate is released, more cells in the area are injured, edema increases, and the cascade spreads to undamaged neurons.

Fluid and Electrolyte Imbalances

In addition to events at the cellular level, injury of the hypothalamus and the pituitary gland from forces transmitted to the head on impact, along with cerebral edema, often results in fluid and electrolyte disturbances that profoundly affect morbidity and mortality in TBI patients. Three common electrolyte imbalances are associated with the hypothalamic-pituitary dysfunction experienced by patients with TBI: central neurogenic diabetes insipidus (CNDI), syndrome of inappropriate secretion of antidiuretic hormone (SIADH), and cerebral salt-wasting syndrome (CSWS). CNDI is associated with hypernatremia, whereas SIADH and CSWS are associated with hyponatremia. Early recognition of all 3 syndromes is important in patients with TBI to prevent further neurological deterioration.

The pituitary gland, the pituitary stalk, and the hypothalamus are vulnerable to injury from head trauma. The hypothalamic-neurohypophyseal system is a collection of nuclei and tracts located in the hypothalamus and the pituitary gland that regulate body water balance. The paraventricular and supraoptic nuclei located in the

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hormone (ADH). ADH, which affects water balance by promoting reabsorption of water in the distal convoluted tubules and collecting ducts in the kidney, combines with a carrier protein called neurophysin. Together, neurophysin and ADH travel down the pituitary stalk and infundibulum through terminal nerve fibers to the pituitary gland. The ADH produced in the hypothalamus is stored in secretory granules in the posterior part of the pituitary gland, where the hormone can be released into the blood. The function of ADH is to maintain normal circulating blood volume. The ADH produced in the hypothalamus is stored in secretory granules in the posterior part of the pituitary gland, where the hormone can be released into the blood. The function of ADH is to maintain normal circulating blood volume.3 Impulses from the baroreceptors are transmitted through the vagus and glossopharyngeal nerves to the paraventricular and supraoptic nuclei in the hypothalamus. Increases in blood volume and blood pressure result in decreased ADH secretion. In patients with hypotension and hypovolemia (common in patients with TBI), secretion of ADH is increased, resulting in conservation of body fluids. Even a 5% to 10% decrease in blood volume or a 5% decrease in mean arterial pressure can stimulate the release of ADH.3

In general, the body first regulates ADH secretion in response to osmoregulation (concentration of body fluids). However, in severe volume depletion (hypotension or blood loss) baroreceptor stimulation of ADH takes precedence over osmoregulation.

Central Neurogenic Diabetes Insipidus

CNDI is characterized by an abnormal increase in urine output, an increase in fluid intake, and thirst due to decreased secretion of ADH, resulting in elimination of extracellular fluid. In trauma patients, CNDI is usually due to damage of the posterior part of the pituitary gland where ADH is stored and secreted.3 In patients with neurological conditions, CNDI is often associated with neurosurgery, tumors, increased intracranial pressure, brain death, and central nervous system infections such as meningitis or encephalitis.3 CNDI occurs in up to 16% of all brain-injured patients and usually occurs 5 to 10 days after trauma.7 CNDI usually occurs in 3 phases. The first phase consists of polyuria (large volumes of dilute urine, 250 mL/h), polydipsia (extreme thirst in patients who are awake and alert), hypovolemia, and hypernatremia.5,6 Urinary specific gravity is less than 1.005 (normal, 1.005-1.030), urine osmolality is less than 200 mOsm/kg, serum osmolality is elevated (>295 mOsm/kg), the serum level of sodium is elevated (>145 mEq/L), and the urinary level of sodium is markedly decreased. Marked urinary losses of other electrolytes (potassium and magnesium) may occur simultaneously. Patients may also have weight loss of approximately 3% to 5% of body weight. Hypovolemia associated with CNDI in patients with TBI results in severe dehydration and further worsening of electrolyte balance.

Diagnosis. Diagnosis of CNDI in patients with TBI is based on clinical signs and symptoms and laboratory findings, specifically polyuria, low urinary specific gravity, low urine osmolality, hypernatremia, and elevated serum osmolality (see Table).
The goal in CNDI is to correct the ADH deficiency and restore fluid balance by promoting sodium and water reabsorption. In the acute phase of CNDI, exogenous ADH is provided, and fluid equivalent to the amount of urine output is given either orally, if the patient can tolerate adequate oral intake, or intravenously. Patients with intact thirst centers who are able to take fluids orally are encouraged to drink as much as possible when thirsty to keep up with fluid losses. However, in patients with TBI, complications from impaired level of consciousness, sensory and motor deficits, and dysphagia often preclude oral

<table>
<thead>
<tr>
<th>Feature</th>
<th>Central neurogenic diabetes insipidus</th>
<th>Syndrome of inappropriate secretion of antidiuretic hormone (ADH)</th>
<th>Cerebral salt-wasting syndrome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>Fluid imbalance due to decreased secretion of ADH in the posterior lobe of the pituitary gland or to renal unresponsiveness to the release of ADH</td>
<td>Persistent production or over-production of ADH resulting in water intoxication and a volume-expanded state</td>
<td>Renal loss of sodium leading to true hyponatremia and a volume- contracted state in which the kidneys do not reabsorb sodium</td>
</tr>
<tr>
<td>Cause</td>
<td>Hypotension, stress, pain, anxiety, and an upright position. Trauma, surgery, or damage of the hypothalamus</td>
<td>Head trauma, brain tumor, abscess, subarachnoid hemorrhage, hydrocephalus, meningitis, encephalitis, Guillain-Barré syndrome, Pneumonia</td>
<td>Cause unclear but often occurs in patients with intracranial abnormalities (head trauma, stroke, subarachnoid hemorrhage, brain tumors) Loss of both intravascular fluid and sodium</td>
</tr>
<tr>
<td>Serum level of sodium, mEq/L</td>
<td>Hypernatremia (&gt;145 high)</td>
<td>Hyponatremia (&lt;135 low)</td>
<td>Hyponatremia (&lt;135 low)</td>
</tr>
<tr>
<td>Serum osmolality, mOsm/kg</td>
<td>&gt;295 (high)</td>
<td>&lt;275 (low)</td>
<td>&lt;275 (low)</td>
</tr>
<tr>
<td>Urinary osmolality, mOsm/kg</td>
<td>Decreased (&lt;200)</td>
<td>Elevated (&gt;100)</td>
<td>Elevated (&gt;100)</td>
</tr>
<tr>
<td>Urinary level of sodium, mEq/L</td>
<td>Within normal reference range or decreased</td>
<td>Within normal reference range or elevated (&gt;25)</td>
<td>Elevated (&gt;25)</td>
</tr>
<tr>
<td>Urine output</td>
<td>Increased (&gt;250 mL/h)</td>
<td>Decreased (400-500 mL/24 h)</td>
<td>Decreased</td>
</tr>
<tr>
<td>Urinary specific gravity</td>
<td>&lt;1.005 (very dilute)</td>
<td>&gt;1.010 (concentrated, dark)</td>
<td>&gt;1.010 (concentrated, dark)</td>
</tr>
<tr>
<td>Extracellular fluid volume</td>
<td>Decreased</td>
<td>Increased</td>
<td>Decreased</td>
</tr>
<tr>
<td>Serum urea nitrogen</td>
<td>Elevated</td>
<td>Normal or low (dilutional)</td>
<td>Elevated</td>
</tr>
<tr>
<td>Mental status</td>
<td>Normal to impaired</td>
<td>Confusion Lethargy</td>
<td>Decreased level of consciousness, agitation, coma</td>
</tr>
<tr>
<td>Body weight</td>
<td>Decreased</td>
<td>Normal or increased</td>
<td>Decreased</td>
</tr>
<tr>
<td>Heart rate</td>
<td>Tachycardia</td>
<td>Slow or normal</td>
<td>Resting or postural tachycardia</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>Normal to mildly hypertensive progressing to hypotension</td>
<td>Hypertensive</td>
<td>Postural hypotension</td>
</tr>
<tr>
<td>Treatment</td>
<td>Fluid replacement (0.45% saline intravenously replaced milliliter for milliliter, or greater), ADH replacement with desmopressin acetate intranasally or orally, lypressin intranasally, or aqueous vasopressin intravenously</td>
<td>Fluid restriction (800-1000 mL/24 h), Slow sodium replacement with normal saline or hypertonic (3%-5%) saline intravenously</td>
<td>Replacement of fluid volume and sodium No restriction of fluids Slow sodium replacement with hypertonic (3%) saline intravenously</td>
</tr>
</tbody>
</table>
intake, and intravenous solutions are required to meet the fluid demands. Intravenous hypotonic solutions most often used to replace lost body fluids include 0.45% saline titrated hourly to replace urine output.1

Exogenous ADH, either desmopressin (DDAVP), vasopressin, or lypressin, may be administered. Desmopressin can be administered nasally 5 to 2 μg/d in divided doses or parenterally 5 to 40 μg/d in daily divided doses.2 Vasopressin (aqueous Pitressin) can be administered intravenously 0.5 to 2 U every 3 hours for patients who have urine output of more than 300 mL/h for 2 consecutive hours. A vasopressin infusion may become necessary, which can be started at 0.2 U/min and titrated to a maximum dose of 0.9 U/min.3 Lypressin dosage is 5 to 20 U 3 to 7 times per day nasally.5

The following formula can be used to calculate the body water deficit (amount of fluid lost).

\[
(0.6 \,[\text{weight in kilograms}] \times (\text{serum sodium} \cdot 140) \div 140 = \text{body water deficit (in liters)}
\]

For example, a patient with a serum sodium level of 150 mEq/L who weighs 70 kg would have a 3-L deficit:

\[
(0.6 \,[70] \times (150 - 140) \div 140 = 3 \, \text{L}
\]

The resulting body water deficit can be used to calculate the volume of replacement fluids needed to restore hemodynamic stability in patients whose condition is unstable.3

Nursing Interventions. Caring for patients in the acute phase of CNDI requires monitoring of several parameters. Fluid intake and urinary output must be determined every 1 to 2 hours. Because the level of consciousness is usually impaired in patients with TBI, an indwelling urinary catheter is necessary to monitor urine output accurately. Urinary output in the acute phase can be extraordinary: more than 250 to 800 mL/h (3-20 L/d). Urinary output greater than 200 mL/h for more than 2 consecutive hours should be reported to a physician.3 Urinary specific gravity should be determined every 1 to 2 hours; low specific gravity (<1.005) indicates that the kidneys are not concentrating urine. Serum osmolality and electrolyte levels, specifically sodium and potassium levels, should be measured at least daily, and frequently more often, depending on the findings and the patient’s hemodynamic stability. Body weight should be determined daily, and patients should be assessed daily for signs and symptoms of worsening dehydration such as decreased skin turgor, dry mucous membranes, tachycardia, and hypotension. Trends are important. Is the patient getting worse? Or is the patient getting better? What do the laboratory values indicate?

Syndrome of Inappropriate Secretion of Antiuretic Hormone

SIADH is characterized by abnormally high levels or continuous secretion of ADH, causing renal reabsorption and retention of water.10 Water is continually being reabsorbed by the kidneys, leading to concentrated urine, fluid retention, and hyponatremia. Hyponatremia is the most common electrolyte problem in patients with neurological problems and is particularly common after TBI; up to 33% of patients with TBI have hyponatremia.8,11

Pathophysiologically, the negative feedback mechanisms that control the release of ADH do not function. In the general population of hospitalized patients, many precipitating factors can cause SIADH: bronchogenic carcinoma, lung disease, pneumonia, positive-pressure breathing during mechanical ventilation, and certain medications (eg, morphine, chlorpromazine, chlorpropamide, chlorothiazide, carbamazepine, and acetaminophen). Conditions that cause SIADH in patients with TBI include traumatic subarachnoid hemorrhage, increased intracranial pressure, and injury of the hypothalamic-neurohypophyseal system. The damage of the hypothalamic-pituitary region that causes ADH dysfunction results in increases in water reabsorption by the renal tubules, decreases in urine volume, fluid retention, and extracellular volume expansion.2 Patients experience excessive water retention and dilutional hyponatremia with a 5% to 10% increase in body weight due to expansion of extracellular volume.5

Signs and Symptoms. The signs and symptoms of SIADH include decreased urinary output, to less than 400 to 500 mL/24 hours, and generalized weight gain due to excess fluid retention.11 Laboratory findings include low serum levels of sodium (<135 mEq/L), serum hypoosmolality (<275 mOsm/L), elevated urinary levels of sodium (>25 mEq/L), and elevated urine osmolality (greater than serum osmolality).5

Diagnosis. Diagnosis of SIADH is based on the clinical signs and symptoms and laboratory findings. Complications due to SIADH and hyponatremia include fluid retention, headache, nausea, vomiting, muscle twitching, fatigue, confusion, lethargy, and, possibly, seizures.
(usually in patients with a serum level of sodium <120 mEq/L). In patients with TBI, the underlying pathological changes result in hyponatremia due to excessive ADH release, which causes renal reabsorption of water and expansion of extracellular volume.

**Treatment.** The treatment of SIADH is focused on fluid restriction (<1000 mL/24 h) and slow, careful replacement of sodium with an intravenous hypertonic solution of sodium chloride (3% saline) and/or diuretics such as furosemide. Medications to suppress ADH activity (demeclocycline hydrochloride) or inhibit renal response to ADH (lithium carbonate) are also options.

Administration of hypertonic intravenous solutions such as 3% sodium chloride requires careful titration because a too-rapid correction of hyponatremia can result in central pontine myelinolysis, an irreversible demyelination of the neurons in the pons of the brain stem. The exact mechanism that causes demyelination is unknown; the recommended rate of serum sodium correction is 10 to 20 mEq/d.

**Nursing Management.** Nursing management for patients with SIADH and hyponatremia is comparable to the management of patients with CNDI. Intake of fluids, urinary output, and urinary specific gravity should be determined every 1 to 2 hours. Urinary and serum levels of electrolytes and osmolality should be monitored. Patients should be assessed for signs and symptoms of worsening outcome. Accurate body weights should be recorded daily for the purpose of monitoring fluid retention. Patients with SIADH require frequent oral care because fluid restriction causes dry mouth. Indications of improvement include correction of low serum levels of sodium, lowered urine osmolality, lowered urinary levels of sodium, and increased serum osmolality.

**Cerebral Salt-Wasting Syndrome**

Unlike SIADH, CSWS is characterized by a true hyponatremia, that is, hyponatremia that results in a loss of both sodium and extracellular fluid. Even though ADH levels are elevated in patients with CSWS, the body loses extracellular fluid and plasma volume decreases, resulting in decreased body weight (volume-contacted state). The pathophysiology of CSWS is unclear but is thought to be due to multiple mechanisms that affect sodium and water balance. The primary pathogenic mechanism is renal loss of sodium, which leads to hyponatremia and a decrease in extracellular volume. Although the syndrome occurs most often in patients with stroke, intracerebral hemorrhage, subarachnoid hemorrhage, and intracranial surgery, it may develop in patients with TBI who have increased intracranial pressure.

**Signs and Symptoms.** Patients with CSWS may report headache and increased thirst. Clinical indications include orthostatic hypotension, tachycardia, dehydration, weight loss, dry mucous membranes, lethargy, decreased level of consciousness, seizures, and coma.

**Diagnosis.** The diagnosis of CSWS is based on the clinical manifestations and the following laboratory findings: primary hyponatremia, serum hypoosmolality, elevated urine osmolality, elevated urinary levels of sodium, increased levels of serum urea nitrogen, increased hematocrit, and increased urinary specific gravity. Even though the mechanism of CSWS is not well understood, the primary distinction between CSWS and SIADH is volume status. Indications of volume depletion (hypotension, weight loss, and decreased skin turgor) occur with CSWS, whereas indications of volume expansion occur with SIADH (decreased urine output and generalized weight gain due to fluid retention).

**Treatment.** Determining the cause (SIADH or CSWS) of hyponatremia in trauma patients is important. SIADH requires strict fluid restriction and/or slow, judicious administration of hypertonic saline, whereas CSWS requires replacement of fluid volume with physiological saline and intravenous replacement with hypertonic 3% sodium chloride solution. As in treatment of SIADH, hypertonic solutions (3% sodium chloride) must be administered slowly because too-rapid correction of hyponatremia can result in central pontine myelinolysis. In patients who tolerate oral intake, fluid can be replaced orally, often with salt tablet supplements.

Restriction of fluids is contraindicated in patients with CSWS. If fluids are restricted, patients will be at risk for cerebral vasospasm, cerebral ischemia, and/or infarction. Other medical interventions may include treatment with fludrocortisone acetate to increase absorption of sodium by the renal tubules.

**Nursing Management.** Nursing management of patients with CSWS is comparable to that of patients with CNDI or SIADH. Isotonic or hypertonic fluids are administered intravenously to obtain positive fluid balance.
balance and correct volume depletion. Sodium can also be replaced orally. Cardiac status should be monitored to detect side effects of medications and fluid volume status. The goal of treatment of CSWS is to replace sodium and fluid volume with intravenous saline or salt tablets. Fluid restriction is definitely contraindicated and can worsen neurological outcomes.

Summary

Caring for patients with complex neurological problems, specifically patients with TBI and electrolyte imbalances, can be challenging. Understanding and recognizing the signs and symptoms of CNDI, SIADH, and CSWS will guide nurses in the appropriate actions to take to avoid deterioration in a patient’s condition. In summary, CNDI is a hypernatremia characterized by elevated serum levels of sodium and serum osmolality, but low urine specific gravity. Patients have large-volume urinary output and extreme thirst. Treatment is replacement of fluid volume either orally or intravenously or treatment with ADH.

SIADH and CSWS are both characterized by hyponatremia. Signs and symptoms are remarkably similar; however, patients with CSWS experiences a true loss of sodium and intravascular fluid. Both sodium and fluid must be replaced to correct the imbalance. In patients with SIADH, sodium is replaced, but fluid is restricted. Monitoring patients for trends in neurological status, laboratory findings, and physiological parameters will guide nurses in determining whether treatment is effective or not.

References


1. Which of the following groups is at greatest risk of death from a traumatic brain injury (TBI)?
   a. Young children (0-4 years old)
   b. Adolescents (15-19 years old)
   c. Young adults (20-27 years old)
   d. Older adults (older than 75 years)

2. Which of the following is the most common cause of TBI?
   a. Falls
   b. Motor vehicle crashes
   c. Sports-related injuries
   d. Penetrating trauma

3. Which of the following types of TBI is a patient injured in a rear end collision most likely to experience?
   a. Penetrating injury
   b. Acceleration-deceleration injury
   c. Direct injury
   d. Hemorrhagic injury

4. What is the role of glutamine in secondary brain injury?
   a. Lactic acid is produced.
   b. ADH is secreted.
   c. The collecting tubules decrease water reabsorption.
   d. Adenosine triphosphate is produced.

5. Which of the following disorders is associated with hypernatremia?
   a. Central neurogenic diabetes insipidus (CNDI)
   b. Syndrome of inappropriate secretion of antidiuretic hormone (SIADH)
   c. Cerebral salt-wasting syndrome (CSWS)
   d. TBI

6. Where is antidiuretic hormone (ADH) stored in the body?
   a. Infundibulum
   b. Hypothalamus
   c. Posterior pituitary gland
   d. Kidney

7. When the serum osmolality is 300 mOsm/kg, which of the following would occur?
   a. Adenosine triphosphate is produced.
   b. ADH is secreted.
   c. The collecting tubules decrease water reabsorption.
   d. Lactic acid is produced.

Test answers: Mark only one box for your answer to each question. You may photocopy this form.

1. a  2. b  3. a  4. a  5. a  6. a  7. a  8. a  9. a  10. a  11. a  12. a
   b  b  b  b  b  b  b  b  b  b  b  b
   c  c  c  c  c  c  c  c  c  c  c  c
   d  d  d  d  d  d  d  d  d  d  d  d

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