progress to convulsions and coma (see also Hyponatraemia, below).

Treatment
Mild water intoxication can be treated simply by restriction of intake (to 1000 mL or even 500 mL per day); in more severe cases 0.9% saline or occasionally hypertonic saline may be required (see section on treatment of hyponatraemia, below). If renal function is impaired, hypertonic saline may be dangerous and dialysis will be required. In some patients with inappropriate ADH secretion, fluid restriction alone may be insufficient and in such cases drugs that antagonize ADH (e.g. demeclocycline) may be used to induce nephrogenic diabetes insipidus.

HYPONATRAEMIA
Causes and clinical features
A low plasma sodium (< 135 mmol/L) can be caused by water intoxication, or by depletion of total body sodium, although changes in plasma sodium are usually a reflection of changes in water rather than sodium balance. Some commonly encountered causes and contributing factors are:

- diuretic therapy;
- psychogenic polydipsia (a common cause of hyponatraemia, but a rare cause of admission to the intensive care unit (ICU));
- renal disease;
- cardiac failure;
- end-stage liver disease;
- fluid losses from the alimentary tract or intra-abdominal drains;
- syndrome of inappropriate ADH.

Hyponatraemia is often precipitated by the use of hypotonic intravenous fluids (e.g. 5% dextrose, 0.18% saline in dextrose 4%) to replace isotonic losses (e.g. from the alimentary tract) or to maintain blood sugar levels in hepatic insufficiency.

Despite repeated warnings (Lane and Allen, 1999) postoperative hyponatraemia remains common, perhaps especially in women undergoing orthopaedic surgery, and is usually attributable to the routine administration of large volumes of isotonic dextrose to patients whose ADH levels have risen in response to the stress of surgery. The risk of hyponatraemia is further increased in the elderly, in whom the ability to handle a water load is impaired, and by long-term preoperative treatment with thiazide diuretics.

Early symptoms of hyponatraemia include progressive headache, nausea, vomiting and weakness. Often the significance of these symptoms is not recognized and if not treated the patient may progress to obtundation, hallucinations, decorticate posturing, myoclonic jerks, seizures, respiratory arrest, coma and brain damage or death. Premenopausal women with hyponatraemic encephalopathy are at particular risk of developing brain damage, whereas men and postmenopausal women are far less likely to develop encephalopathy. Thus premenopausal women and children are at risk of brain damage at sodium concentrations as high as 128 mmol/L, whereas postmenopausal women do not usually become symptomatic until sodium concentrations have fallen below 120 mmol/L, although symptoms can occur at higher levels if the rate of change is rapid.

The true nature of a cause of hyponatraemia in the critically ill, the ‘sick-cell syndrome’ (Flear and Singh, 1973), is still controversial. This syndrome was thought to occur only in the most severely ill patients and was said to account for the close association between a low plasma sodium and a poor prognosis. It was postulated that a defect at cellular level, possibly a failure of the sodium pump due to an inadequate supply of energy in the form of adenosine triphosphate (ATP), causes sodium to enter the cell in exchange for potassium ions, which are then lost in the urine. An alternative explanation has been that this abnormality is simply a response to total body potassium depletion that causes intracellular hypotonia and a redistribution of body water. More recently it has been suggested that in critically ill patients intracellular solutes may leak out of the cell because of an increase in membrane permeability and that this could lead to intracellular redistribution of sodium, with an increased osmolar gap. Simultaneous correction of hyponatraemia and the osmolar gap supports this concept of the sick-cell syndrome (Guglielminotti et al., 2002).

Diagnosis
In hyperlipidaemia the plasma sodium concentration may be spuriously low because the sodium is confined to the aqueous phase, whereas its concentration is expressed in terms of the total plasma volume. Significant sodium depletion will cause a fall in intravascular volume and stimulate the release of aldosterone. In true hyponatraemia, therefore, urinary potassium excretion increases while sodium ions are retained. In hyperlipidaemia (or ‘pseudohyponatraemia’) the concentration of other plasma electrolytes (potassium, chloride and bicarbonate) will also be reduced. Failure to recognize pseudohyponatraemia can have dangerous consequences (Editorial, 1980).

When the cause of hyponatraemia is not obvious it is important to exclude:

- Addison’s disease;
- hypothyroidism;
- the syndrome of inappropriate ADH.

Treatment
The brain oedema and raised intracranial pressure associated with hyponatraemia can result in a number of devastating consequences, including central diabetes insipidus, cerebral infarction, cortical blindness and a permanent vegetative state. Hypoxia plays an important role in the genesis of the cerebral damage associated with hyponatraemia and neurological sequelae are almost inevitable in those who suffer a respiratory arrest. Prompt treatment, including
securing the airway, ensuring adequate oxygenation and mechanical ventilation when indicated, is therefore essential.

When there are no symptoms conservative treatment, consisting of eliminating the precipitating cause, including correction of any hormone deficiency (e.g. cortisol, aldosterone, thyroid hormone), and simple water deprivation is the preferred course of action. Normal saline should be given to those who are volume-depleted. Symptomatic hyponatraemia can be treated with intravenous hypertonic sodium chloride (3%, 514 mmol/L) sometimes combined with administration of a loop diuretic such as furosemide.

Although conventionally too rapid correction of profound, chronic (>2 days) hyponatraemia is thought to increase the risk of precipitating severe shrinkage of brain cells and central pontine myelinolysis (Sterns et al., 1986), it seems that prompt judicious therapy with intravenous sodium chloride before the development of respiratory insufficiency is associated with better outcomes than fluid restriction alone (Ayus and Arieff, 1999). Certainly chronic symptomatic hyponatraemia in postmenopausal women can be associated with serious morbidity and mortality (Ayus and Arieff, 1999) and the risk of not correcting cerebral oedema exceeds the small risk of osmotic demyelination as a result of treatment. Nevertheless, in cases of symptomatic hyponatraemia the rise in plasma sodium should not usually exceed 1–2 mmol/h. The plasma sodium concentration should be monitored frequently (e.g. every 2 hours) and should not be allowed to increase to above about 133 mmol/L. In those with seizures and/or respiratory distress the sodium concentration should be increased more rapidly, for example by about 8–10 mmol/L over the first 4 hours in profound hyponatraemia or until cessation of seizure activity. This rate of correction can only be accomplished using hypertonic saline. Treatment with hypertonic saline should be discontinued when either the patient becomes asymptomatic or the plasma sodium reaches a concentration of between 124 and 132 mmol/L. The plasma sodium should not normally be increased by more than about 20 mmol during the initial 48 hours of treatment and as a general principle should not be rapidly increased to normal or high levels. As a guide, and assuming that water comprises 50% of total bodyweight, 1 mL/kg of 3% sodium chloride will raise the plasma sodium by 1 mmol/L.

A recent multicentre trial demonstrated that in patients with euvoalaemic or hypervolaemic hyponatraemia caused by chronic heart failure, cirrhosis or the syndrome of inappropriate ADH an oral vasopressin V₁-receptor antagonist was effective in increasing serum sodium concentrations (Schrier et al., 2006).

HYPERNATRAEMIA (Pavlevsky et al., 1996)
Causes
Hyponatraemia (a plasma sodium > 145 mmol/L) is one of the most commonly encountered electrolyte abnormalities in the hospital population and is seen most often in situations of predominant water depletion (e.g. diabetic coma, diabetes insipidus, fever, elevated ambient temperature, infirmity). It may also occur in association with salt retention in acute renal failure and can be exacerbated by the excessive administration of sodium ions, often as isotonic saline, artificial colloids or 8.4% sodium bicarbonate.

Clinical features
Conscious level is frequently impaired and seizures are common. Associated laboratory abnormalities may include metabolic acidosis, azotaemia, hypophosphataemia and hyperglycaemia. Most patients have severe concomitant disease and hypernatraemia is associated with substantial long-term morbidity and mortality.

Treatment
Associated medical conditions must be treated as a matter of urgency. Pure water depletion should be treated with hypotonic intravenous fluids or dialysis, but rapid falls in plasma sodium greater than 2 mmol/h may precipitate cerebral oedema and must be avoided. Too rapid correction of hypernatraemia has been implicated in the morbidity and mortality of diabetic ketoacidosis (see Chapter 17). When required (e.g. following excessive administration of isotonic saline) solute removal should be accomplished by diuretic therapy or dialysis.

HYPOKALAEMIA
Causes
The normal daily intake of potassium is 50–150 mmol (1–1.5 mmol/kg per day). Hypokalaemia is usually related to inadequate replacement of excessive urinary or gastrointestinal losses (e.g. diarrhoea). For a number of reasons, critically ill patients are particularly prone to the development of hypokalaemia. Elevated levels of aldosterone are found in both cardiac and liver failure, as well as in response to stress, while steroids and diuretics also increase urinary potassium losses. Movement of potassium into cells is promoted by β₂ agonists, insulin, mineralocorticoids and theophyllines. Also potassium may be lost in the urine during the recovery phases of acute renal failure, and severe hypokalaemia may itself lead to tubular dysfunction. Severe vomiting may be accompanied by a hypochloroaemic alkalosis which leads to a shift of potassium into the cells and increased potassium losses from the kidney. Conversely, acidosis favours the movement of potassium out of cells in exchange for hydrogen ions. These changes in plasma potassium are more marked with metabolic than with respiratory acid–base disturbances.

Clinical features and diagnosis
Plasma potassium levels are not always a good guide to total body potassium, which may be significantly depleted even when the patient is normokalaemic. In this situation the diagnosis is suggested by finding a metabolic alkalosis with a paradoxically acid urine, caused by renal conservation of


