REVIEW ARTICLE

DISORDERS OF FLUIDS AND ELECTROLYTES
Julie R. Ingelfinger, M.D., *Editor*

Maintenance Intravenous Fluids in Acutely Ill Patients

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A critical aspect of the care of acutely ill patients is the administration of intravenous fluids. Intravenous fluids may be required as a bolus infusion for resuscitation or as a continuous infusion when sufficient fluids cannot be ingested orally.

The goal of maintenance intravenous fluids is to preserve the extracellular volume while maintaining a normal electrolyte balance. An appropriate maintenance fluid provides an adequate quantity of both water and electrolytes to ensure good tissue perfusion without causing complications related to fluid overload or volume depletion. It also prevents the development of hyponatremia, hypernatremia, and other electrolyte imbalances.

Despite the almost ubiquitous need for intravenous fluids in acutely ill patients, there has been little consensus on the most appropriate rate of administration and composition of intravenous fluids, and practice patterns with respect to maintenance fluids vary widely.[1-3] In addition, acutely ill patients frequently have conditions that impair normal water and electrolyte homeostasis (Table 1), and choosing the appropriate volume and composition of intravenous fluids requires great care.[4]

Intravenous fluids can be classified, according to the concentration of sodium plus potassium in the fluid, as being either isotonic (approximately equal to the plasma sodium concentration) or hypotonic (less than the plasma sodium concentration). The dextrose content of intravenous fluids has no effect on the tonicity, since the dextrose is rapidly metabolized when it enters the bloodstream and should not produce hyperglycemia.

A prevailing practice has been to administer hypotonic maintenance intravenous fluids in both children and adults.[1,5,6] This practice has been associated with a high incidence of hospital-acquired hyponatremia and more than 100 reports of iatrogenic deaths or permanent neurologic impairment related to hyponatremic encephalopathy,[7-11] since acutely ill patients may have disease states associated with an excess of arginine vasopressin (AVP) (Fig. 1). This excess impairs excretion of free water and may aggravate hyponatremia.[15,16]

Over the past decade, many studies have evaluated the association between the composition and quantity of maintenance fluids and the development of hyponatremia. Recent data also suggest that rapid volume expansion with 0.9% saline (normal saline), as compared with balanced electrolyte solutions, may result in untoward complications.[17] The current review considers the physiological principles that guide the appropriate selection of intravenous fluids, as well as the recent literature evaluating the safety of various intravenous fluids with respect to their composition and rate of administration.

AVP AND DISORDERS OF SODIUM AND WATER HOMEOSTASIS

The human body has a remarkable ability to maintain a normal composition of body water and plasma osmolality, despite wide variations in fluid and electrolyte intake.[18] Sodium and water homeostasis is regulated through the actions of AVP, the renin–angiotensin–aldosterone system, and natriuretic peptides. Plasma osmolality is regulated both by thirst and by excretion of free water. In a patient who can ingest nothing by mouth, plasma osmolality is primarily under the control of AVP release, which determines the rate of free-water excretion.[12] Any disease state that results in either excess AVP or impaired AVP action will place a patient at risk for a plasma sodium concentration that is too high or too low.

There are numerous hemodynamic and nonhemodynamic stimuli for AVP secretion; thus, virtually all acutely ill hospitalized patients are at risk for hyponatremia (Fig. 1). Hemodynamic stimuli for AVP production include volume depletion; hypotension; edematous states such as congestive heart failure, cirrhosis, and the nephrotic syndrome; and sepsis.[13] Nonhemodynamic physiological stimuli for AVP secretion include pain, stress, nausea, vomiting, hypoxemia, hypercapnia, hypoglycemia, and the perioperative state.[12,14]

These physiological stimuli can result in increased AVP levels in the absence of volume depletion or hyperosmolality.[12] In addition, an ever-expanding list of conditions and medications is associated with the syndrome of inappropriate antidiuresis, in which AVP excess occurs in the absence of any identifiable nonosmotic stimuli for AVP production.[19] The conditions most often associated with this syndrome are cancer, central nervous system (CNS) disorders, pulmonary disorders, and infections.[19] Medications that are frequently associated with this syndrome include narcotics, the chemotherapeutic agents cyclophosphamide and vincristine, selective serotonin-reuptake inhibitors, the antiepileptic agent oxcarbazepine, and the recreational drug "ecstasy" (3,4-methylenedioxymethamphetamine [MDMA]). Thiazide diuretics can also be associated with a condition that resembles the syndrome of inappropriate antidiuresis. The syndrome of inappropriate antidiuresis is now recognized as the most common cause of euvolemic hyponatremia.[20]

Table 1. Conditions Requiring Special Considerations in Maintenance Fluid Therapy.

Free-water restriction for euvolemic states of AVP excess
CNS disturbances
Meningitis
Encephalitis
Brain tumors
Head injury
Cerebritis
Subarachnoid hemorrhage
Pulmonary disease
Pneumonia
Asthma
Bronchiolitis
Tuberculosis
Cancer
Postoperative state
Fluid restriction for edematous states
Congestive heart failure
Nephrosis
Cirrhosis
Fluid and sodium restriction for oliguric states
Acute glomerulonephritis
Acute tubular necrosis
End-stage renal disease
Increased free-water requirements for renal concentrating defects
Congenital nephrogenic diabetes insipidus
Sickle cell disease
Obstructive uropathy
Reflux nephropathy
Renal dysplasia
Nephronophthisis
Tubulointerstitial nephritis
Use of lithium
Increased sodium and water requirements for solute diuresis
Diuretic phase of acute tubular necrosis
Postobstructive diuresis
Immediate postoperative renal transplantation
Diabetic ketoacidosis
Bartter's syndrome
Fanconi's syndrome
Cerebral salt wasting
Adrenal insufficiency
Increased free-water requirements for extrarenal free-water losses
Burns
Prematurity in neonates
Fever
Infectious diarrhea

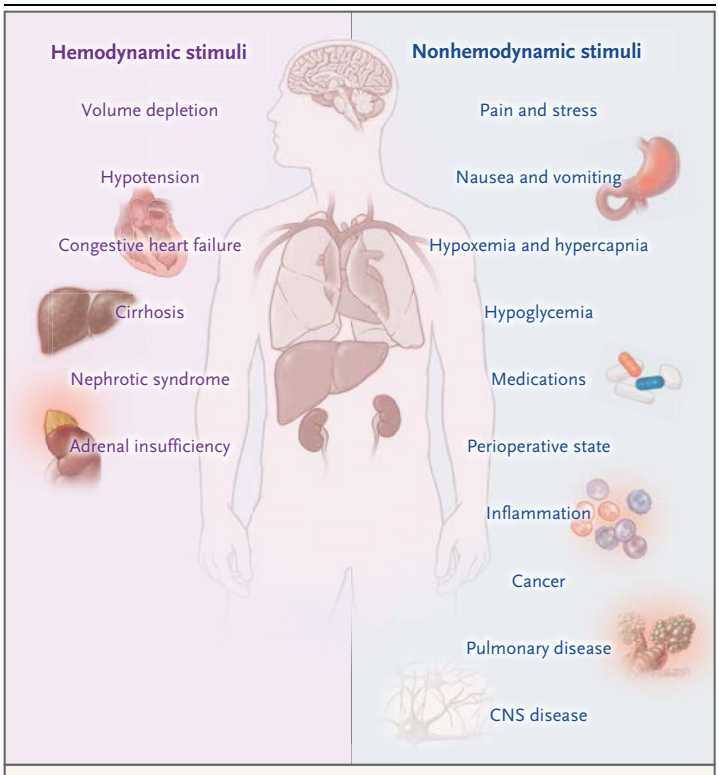

Figure 1. Nonosmotic States of Arginine Vasopressin (AVP) Excess.

Numerous hemodynamic and nonhemodynamic stimuli for AVP secretion place virtually all acutely ill hospitalized patients at risk for the development of hyponatremia. Physiological stimuli can result in an increase in AVP levels in the absence of volume depletion or hyperosmolality. In numerous disease states and medications associated with the syndrome of inappropriate antidiuresis, AVP excess occurs in the absence of any identifiable nonosmotic stimuli for AVP production.[12-14]

The ability to produce concentrated urine depends on both the ability to maintain a concentrated renal medullary interstitium and the water permeability of the collecting duct in response to AVP. Diseases or medications that disrupt the medullary interstitium or interfere with the action of AVP will result in a renal concentrating defect and can lead to hypernatremia in patients with restricted access to free water (Table 1).[21] Common reasons for a renal concentrating defect include tubulointerstitial renal diseases such as obstructive uropathy and sickle cell disease, genetic disorders such as congenital nephrogenic diabetes insipidus, and the use of lithium.

HOSPITAL-ACQUIRED HYPONATREMIA

Hyponatremia, which is defined as a plasma sodium concentration of less than 135 mmol per liter, is the most common electrolyte abnormality in hospitalized patients; it affects approximately 15 to 30% of children and adults who are hospitalized.[22,23] Most hyponatremia in these patients is hospital-acquired and is related to the administration of hypotonic intravenous fluids in patients with elevated AVP levels.[16,23-26] Virtually all studies evaluating hospital-acquired hyponatremia have shown that it is related to the administration of hypotonic fluids.[23,24,27-30]

The most serious complication of hospital-acquired hyponatremia is hyponatremic encephalopathy, which is a medical emergency that can be fatal or lead to irreversible brain injury if it is inadequately treated.[7,10] All large studies of hospital-acquired hyponatremic encephalopathy have involved primarily otherwise healthy children and adults who were receiving hypotonic fluids; in many cases, this condition followed minor surgical procedures.[7,8,10,11,31] The strong association between the use of hypotonic fluid and hyponatremic encephalopathy and the number of preventable deaths in children that have resulted from the use of hypotonic fluid have drawn the attention of the National Patient Safety Agency in the United Kingdom[32] and the Institute for Safe Medication Practices of Canada[33] and the United States.[34,35] All three organizations have issued warnings about the dangers of administering hypotonic fluids in children and have called for the establishment of and adherence to guidelines for administration of fluid. Similar patient-safety warnings have not, however, been issued for adults.

Patients with hospital-acquired hyponatremia are at particular risk for the development of hyponatremic encephalopathy, which usually develops acutely, in less than 48 hours, leaving little time for brain adaptation. Hospitalized patients who are at particular risk for the development of hyponatremic encephalopathy at even mildly hyponatremic levels include children younger than 16 years of age,[8] women in their reproductive years,[7] and patients with hypoxemia[36] or underlying CNS disease,[37] since these conditions either impair regulation of brain-cell volume or are associated with decreased intracranial capacity for brain expansion (Table 2).

Prevention of hospital-acquired hyponatremic encephalopathy is critical, since the presenting symptoms are nonspecific and can be easily overlooked until advanced symptoms develop.

The most consistent symptoms of hyponatremic encephalopathy are headache, nausea, vomiting, and generalized weakness.[7,38,39] Advanced symptoms of hyponatremic encephalopathy include seizures, respiratory arrest, noncardiogenic pulmonary edema, and decorticate posturing.[7,38,39] Symptoms can occur abruptly and do not always correlate with the plasma sodium concentration or the rapidity of development of hyponatremia.[7,10,38,40]

Failure to recognize and treat hyponatremic encephalopathy with hypertonic saline results in a poor neurologic prognosis.[7,10] Fluid restriction alone, isotonic fluids, and vaptans have no role in the immediate management of hyponatremic encephalopathy.[14,39]

Mounting data show that even chronic hyponatremia, which develops over a period of 48 hours or longer, without apparent neurologic symptoms, is deleterious. Chronic hyponatremia has been shown to result in subtle neurologic impairment, which can cause gait disturbances that lead to falls and associated bone fractures in the elderly, with increased bone fragility resulting from bone demineralization.[41-45]

Hyponatremia is an independent risk factor for death in the hospital setting, particularly among patients with end-stage liver disease, congestive heart failure, pneumonia, and end-stage renal disease, and it is associated with increased hospital costs, length of hospital stay, and rates of readmission.[46-50] When hyponatremia develops, it can be difficult to correct, since most initial therapies, such as fluid restriction and isotonic fluids, are relatively ineffective in correcting euvolemic and hypervolemic hyponatremia.[20] For all these reasons, strategies should be implemented to prevent hyponatremia.

Table 2. Risk Factors for Hyponatremic Encephalopathy.

Risk Factor	Pathophysiological Mechanism
Acute hyponatremia (<48 hr)	Decreased time for brain adaptation
Age <16 yr	Increased ratio of brain to intracranial volume
Female sex	Sex steroids (estrogens) inhibit brain adaptation Increased AVP levels Cerebral vasoconstriction Hypoperfusion of brain tissue
Hypoxemia	Impaired brain adaptation Decreased cerebral perfusion
Brain injury	Vasogenic cerebral edema Cytotoxic cerebral edema

CONCERNS ABOUT HYPOTONIC MAINTENANCE FLUIDS IN CHILDREN AND ADULTS

Hypotonic fluids continue to be recommended as maintenance fluids in acutely ill patients despite the strong association between their use and the development of hospital-acquired hyponatremia.[6,51] The prevailing practice has been to administer hypotonic fluids (e.g., 5% dextrose in a solution of 0.18 to 0.45% saline) at a rate of approximately 2.0 to 3.0 liters per day in adults. The equivalent amount in children is estimated as either of the following: 1500 ml per 1.73 m^2 of body-surface area per 24 hours or, as calculated with the use of the Holliday–Segar formula, 100 ml per kilogram per 24 hours for the first 10 kg of body weight, plus 50 ml per kilogram per 24 hours for a weight of greater than 10 to 20 kg, and an additional 20 ml per kilogram per 24 hours for a weight above 20 kg.[6,52]

Such recommendations are based on theoretical calculations from the 1950s, before the syndrome of inappropriate antidiuresis was recognized as a common clinical entity. In 1953, Talbot et al. made recommendations regarding the administration of fluids in adults according to a theoretical model of the maximal and minimal amount of sodium and water in parenteral fluids that could be administered without adverse effects.[53] In 1957, Holliday and Segar made similar recommendations for children according to average caloric requirements for hospitalized children and electrolyte requirements based on dietary intake.[52] However, these recommendations lack validation in clinical practice in children or adults. All current recommendations regarding the composition and rate of maintenance fluid therapy in children and adults, regardless of the patient's condition, are predominantly opinion-based.[51]

We previously suggested that isotonic fluids should be administered in maintenance intravenous fluids to prevent hospital-acquired hyponatremia in acutely ill children and that the routine practice of administering hypotonic fluids (sodium concentration, <130 mmol per liter) be abandoned because of the increased risk of hyponatremia.[54] We subsequently extended this recommendation to apply to adult patients.[16]

Currently, to our knowledge, there are no formal society-sponsored guidelines for maintenance fluid therapy in hospitalized patients in the United States. Attempts have been made to develop consensus guidelines for children and adults in the United Kingdom.[6,32,55,56]

The first consensus guideline on fluid therapy was issued by the U.K. National Health Service in 2007. The National Health Service issued a patient-safety alert to remove 0.18% saline from general-use areas (e.g., the emergency department and pediatric ward) for children and recommended 0.45% saline for maintenance fluids for the majority of children and 0.9% saline for children at high risk for hyponatremia.[32] These opinion-based recommendations were subsequently adopted for the care of children in Northern Ireland by the Regulation and Quality Improvement Authority and in Australia by the Victorian Paediatric Clinical Network. Preliminary data suggest that these recommendations may have been helpful in reducing the incidence of hyponatremia.[57]

Even though 0.18% saline was essentially banned throughout the United Kingdom for use in children, consensus guidelines still recommend it as a maintenance fluid in adults.[6,55] The British Consensus Guidelines on Intravenous Fluid Therapy for Adult Surgical Patients, which were published in 2008 and updated in 2011, recommend 0.18 to 0.45% saline for postoperative maintenance fluids.[55] In 2013, the National Institute for Health and Care Excellence guidelines for intravenous fluid therapy in adults, which were published in the United Kingdom, recommended 0.18% saline for maintenance fluids.[6] These guidelines were primarily opinion-based and included low-quality evidence on which to base recommendations. These consensus guidelines lack validation in clinical practice.

ISOTONIC MAINTENANCE FLUIDS FOR THE PREVENTION OF HOSPITAL-ACQUIRED HYPONATREMIA

The use of isotonic fluids in maintenance fluids for the prevention of hospital-acquired hyponatremia in acutely ill patients was initially controversial,[58,59] owing mainly to the potential for unintended consequences. These consequences include the development of hypernatremia, fluid overload with edema or hypertension, and hyperchloremic acidosis.[60]

More than 15 randomized, prospective trials involving more than 2000 patients have evaluated the safety and efficacy of isotonic fluids as compared with hypotonic fluids for the prevention of hyponatremia.[61-66] Most of these studies involved children, the majority of whom were surgical and critical care patients. Isotonic fluids were superior to hypotonic fluids for the prevention of hyponatremia in all but 1 small study,[67] in which 37 patients were followed for approximately 12 hours. Isotonic fluids were not associated with an increased risk of hypernatremia or fluid overload, and there were no apparent serious complications. A meta-analysis of 10 of these studies, involving almost 1000 children, showed that hypotonic fluids were associated with a relative risk of 2.37 for the development of mild hyponatremia (sodium concentration, <135 mmol per liter) and a relative risk of 6.2 for the development of moderate hyponatremia (sodium concentration, <130 mmol per liter).[61] Some physicians have argued that fluid restriction with hypotonic fluids would be sufficient to prevent hyponatremia.[58] In 4 studies, fluid restriction with hypotonic fluids was not effective in preventing hyponatremia.[68-71]

It has also been argued that isotonic fluids may not be necessary for the prevention of hyponatremia in a general pediatric ward. A study involving almost 700 children showed that the odds ratio for prevention of hyponatremia with an isotonic fluid was similar among surgical patients and nonsurgical patients and among patients who were in intensive care and those who were not in intensive care.[62]

Taken together, these studies suggest that isotonic fluids are most appropriate for the vast majority of hospitalized patients who are at risk for elevated AVP levels and hospital-acquired hyponatremia. This does not mean that isotonic fluids are appropriate in all clinical settings or that they are without risk. The studies were of short duration (usually <72 hours) and excluded patients with renal disease, heart failure, and cirrhosis. Precautions were taken if complications were developing. It is not certain whether the side-effect profile with isotonic fluids would be as favorable in other patient populations, such as the elderly, as it is in children.

Isotonic fluids may result in hyponatremia in patients with CNS injury in whom cerebral salt wasting develops or in patients with the syndrome of inappropriate antidiuresis in whom the urine osmolality is greater than 500 mOsm per kilogram.[72] Isotonic fluids could also result in hypernatremia if there is a renal concentrating defect or if there are large extrarenal free-water losses. Any type of intravenous fluid can result in fluid overload if administered in excessive quantities (for example, in patients with end-stage renal disease or heart failure in whom both sodium excretion and water excretion are impaired). In most circumstances, the administration of isotonic fluids should not lead to hypernatremia or fluid overload.[73]

BALANCED SALT SOLUTIONS AS COMPARED WITH 0.9% SALINE

An area of active investigation focuses on the potential for deleterious effects associated with 0.9% saline (normal saline) as compared with those associated with balanced electrolyte solutions (Table 3).[17,74] Normal saline (sodium concentration, 154 mmol per liter) has the same sodium concentration as the aqueous phase of human plasma, but it has a supraphysiologic chloride concentration. Saline solutions may also have a pH that is far lower than that of water (range, 3.5 to 7.0). The low pH of 0.9% saline appears to be related to the polyvinyl chloride bags in which it is packaged, since the pH of 0.9% saline in a glass bottle is 7.0.

Deleterious consequences of 0.9% saline have been associated primarily with studies (both in animals and in humans) in which infusion is rapid and with clinical scenarios in which fluid resuscitation or intraoperative fluid management includes administration of a large volume of fluid.[74] In such circumstances, 0.9% saline, as compared with balanced salt solutions, may produce a hyperchloremic metabolic acidosis, renal vasoconstriction, delayed micturition, an increased incidence of acute kidney injury requiring renal-replacement therapy, and hyperkalemia.

Whether any of these complications will occur when 0.9% saline is used at maintenance rates for less than 72 hours is unclear, but randomized trials that have been sufficiently powered to assess this possibility have not been conducted. Currently, no balanced electrolyte solution is perfectly matched with plasma (Table 3). Multiple electrolytes injection, type 1, USP, (an infusion fluid) has a supraphysiologic buffer concentration of 50 mmol per liter. Ringer's lactate contains calcium and may be incompatible with blood products and some medications. There are insufficient data to suggest that 0.9% saline is unsafe when used as a maintenance fluid.

SELECTING THE RATE OF ADMINISTRATION AND THE COMPOSITION OF MAINTENANCE INTRAVENOUS FLUIDS

No single rate of administration or composition of maintenance intravenous fluids is appropriate in all circumstances. Thus, intravenous fluids may be viewed as medications that require careful dose adjustment that is specific to the disease state of each patient.

The rate of administration and the composition of intravenous fluids need to be individualized, and while patients are receiving intravenous fluids, they require close monitoring with daily measurement of weight, frequent assessment of vital signs, strict measurements of intake and output, and daily measurement of serum electrolyte levels and physical examination. Many children have died of hyponatremic encephalopathy within 24 hours after the initiation of hypotonic intravenous fluids, so even close observation may be inadequate to prevent this complication.

Table 1 lists a broad range of conditions that require special consideration when maintenance fluid therapy is administered, and Figure 2 shows a practical approach for adjusting maintenance intravenous fluids according to these conditions. This approach is opinion-based, since data are lacking from studies evaluating the most appropriate fluid therapy for all conditions.

Dextrose is provided in maintenance fluids to provide sufficient calories to prevent hypoglycemia and limit tissue catabolism, but it does not provide complete nutritional support. Some dextrose-containing saline solutions are hyperosmolar to plasma, but they are not hypertonic, since the dextrose is rapidly metabolized on entering the bloodstream (Table 3). The default maintenance solution for adults is 5% dextrose in a solution of 0.9% saline administered at a rate of 100 to 120 ml per hour; this is based on the fact that most hospitalized patients are at risk for euvolemic hyponatremia from AVP excess if they

Table 3. Composition of Commercially Available Intravenous Crystalloid Solutions for Fluid Therapy.*

Fluid	Glucose	Sodium	Chloride	Potassium	Buffer†	Calcium	Magnesium	pH	Osmolarity	Osmolality	Electrolyte-free Water
	g/dl	*millimoles per liter*							*mOsm/liter*	*mOsm/kg*	%‡
Human plasma	0.07–0.11	135–144	95–105	3.5–5.3	23–30	2.2–2.6	0.8–1.2	7.35–7.45	308	288	0
5% Dextrose in water	5	0	0	0	0	0	0	3.5–6.5	252		100
4% Dextrose in 0.18% saline	4	30	30	0	0	0	0	3.5–6.5	282		81
5% Dextrose in 0.2% saline	5	34	34	0	0	0	0	3.5–6.5	321		78
5% Dextrose in 0.45% saline	5	77	77	0	0	0	0	3.5–6.5	406		50
5% Dextrose Ringer's lactate	5	130	109	4	28	1.5	0	4.0–6.5	525		13
5% Dextrose in 0.9% saline	5	154	154	0	0	0	0	3.5–6.5	560		0
5% Dextrose multiple electrolytes injection, type 1, USP	5	140	98	5	50	0	1.5	4.0–6.5	547		6
Ringer's lactate	0	130	109	4	28	1.35	0	6–7.5	273	254	13
Ringer's acetate	0	130	112	5	27	1	1	6–8	276		12
Hartmann's solution	0	131	111	5	29	2	0	5.0–7.0	278		12
0.9% Saline	0	154	154	0	0	0	0	4.5–7	308	286	0
Multiple electrolytes injection, type 1, USP§	0	140	98	5	50	0	1.5	4.0–6.5	294		6
Isotonic electrolyte solution¶	0	140	127	4	29	2.5	1	4.6–5.4	304		6

* To convert the values for glucose to millimoles per liter, multiply by 0.05551. To convert the values for potassium to milligrams per deciliter, divide by 0.2558. To convert the values for calcium to milligrams per deciliter, divide by 0.250. To convert the values for magnesium to milligrams per deciliter, divide by 0.4114. USP denotes United States Pharmacopeia.

† The buffer is bicarbonate in plasma, lactate in Ringer's lactate and Hartmann's solution, acetate in Ringer's acetate, acetate (27 mmol per liter) and gluconate (23 mmol per liter) in multiple electrolytes injection, type 1, USP, and acetate (23 mmol per liter) and maleate (5 mmol per liter) in isotonic electrolyte solution.

‡ This percentage is based on a sodium plus potassium concentration in the aqueous phase of plasma of 154 mmol per liter, assuming that plasma is 93% water with a plasma sodium concentration of 140 mmol per liter and a potassium concentration of 4 mmol per liter.

§ Multiple electrolytes injection, type 1, USP, is the generic name for Plasma-Lyte 148, Normosol, and Isolyte.

¶ Isotonic electrolyte solution is the generic name for Sterofundin and Ringerfundin. It has an electrolyte composition that is similar to that of plasma.

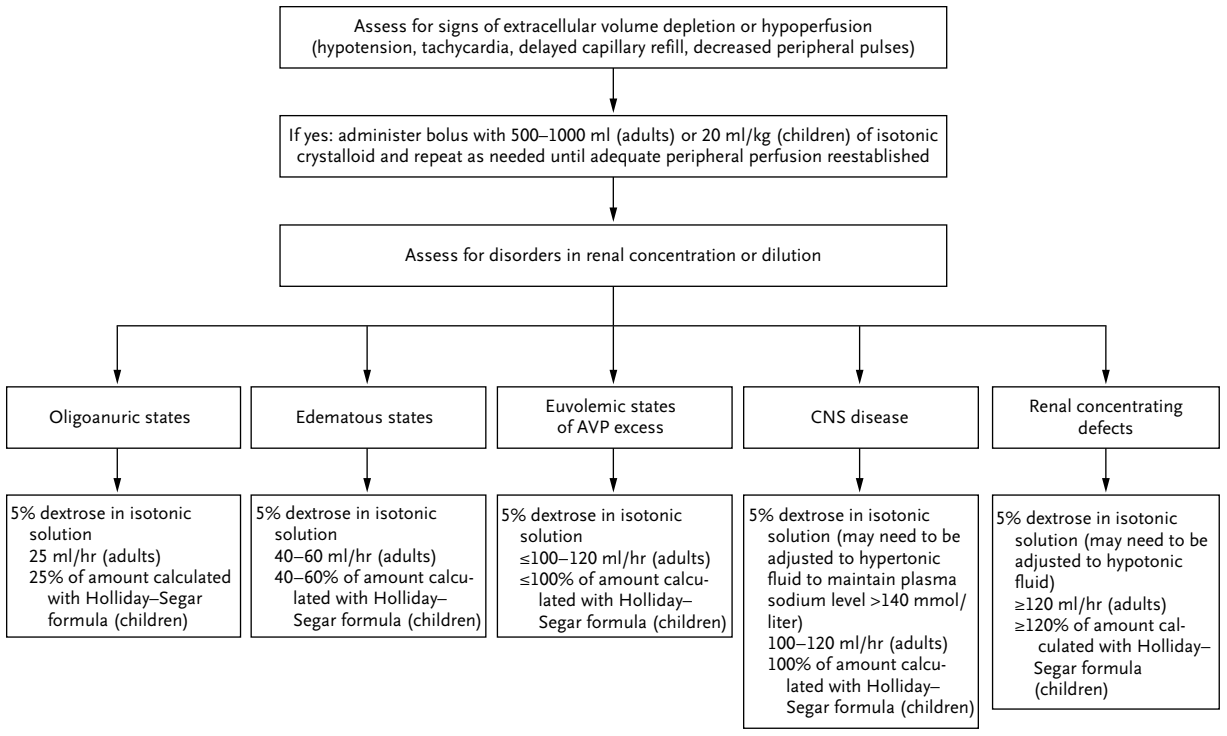

Figure 2. Guide to Maintenance Intravenous Fluid Therapy in Acutely Ill Patients.

Since most hospitalized patients are at risk for hyponatremia from AVP excess, in most acutely ill adults, the safest type of maintenance solution and rate of administration are 5% dextrose in a solution of 0.9% saline at a rate of 100 to 120 ml per hour. In children, the equivalent dose is either 1500 ml per 1.73 m^2 of body-surface area per 24 hours or an amount calculated with the use of the Holliday–Segar formula (100 ml per kilogram per 24 hours for the first 10 kg of body weight, plus 50 ml per kilogram per 24 hours for weight greater than 10 to 20 kg, and an additional 20 ml per kilogram per 24 hours for weight above 20 kg). The rate and composition of intravenous fluids will need to be adjusted for certain conditions. Patients at risk for fluid overload require fluid restriction. Patients with clinically significant renal concentrating defects require an increased volume of hypotonic fluids to keep up with ongoing urinary free-water losses. Hypotonic fluids should be administered only if there is a specific indication, and they should be avoided if hyponatremia is present. In patients with central nervous system (CNS) diseases who are at risk for cerebral edema, the plasma sodium concentration should be maintained at greater than 140 mmol per liter to prevent cytotoxic cerebral edema.

receive hypotonic fluids. Provision of fluids at a rate greater than or less than this amount is determined according to whether there is a disorder in renal concentration or a fluid overload state, respectively. A hypotonic fluid may be required if there is a clinically significant renal concentrating defect with ongoing free-water losses or to aid in the correction of established hypernatremia.[4]

Studies that evaluate the most appropriate maintenance fluid for edematous states are lacking. It is our opinion that an isotonic fluid administered at a restricted rate would be appropriate, since these patients frequently have hyponatremia.

Administration of potassium is not specifically addressed in this review article or in the algorithm in Figure 2. A common practice is to add 20 mmol per liter of potassium to maintenance intravenous fluids, but data to support the safety of this approach are lacking, and it is not clear that adding more than a physiologic concentration of potassium (i.e., >5 mmol per liter) is necessary when intravenous fluids are administered for less than 48 hours, unless hypokalemia or malnutrition is present or diuretics are being used.

SUMMARY

The administration of intravenous fluids is an essential component of supportive care for acutely ill patients. Because of limited evidence,

Box 1. Case 1.

Case 1 illustrates the use of perioperative maintenance therapy.

A 28-year-old woman who weighs 65 kg is admitted through the emergency department with a diagnosis of acute appendicitis. Given a history of poor oral intake, she receives a 1-liter bolus of 0.9% saline in the emergency department. Vital signs and serum electrolyte levels are otherwise normal at presentation. What type and rate of maintenance intravenous fluid would you administer while the patient is receiving nothing by mouth both before surgery and postoperatively?

Answer: An appropriate fluid would be 5% dextrose in a solution of 0.9% saline at a rate of 100 ml per hour. Perioperatively, patients have numerous stimuli for AVP production, including pain, stress, nausea, narcotics administered for pain management, and hypovolemia. In addition, women in their reproductive years are at increased risk for hyponatremic encephalopathy.[7] Administration of 0.9% saline is suitable to maintain the extracellular volume and will reduce the risk of hospital-acquired hyponatremia.

Box 2. Case 2.

Case 2 illustrates maintenance therapy in a patient with CNS disease.

A 75-year-old man who weighs 80 kg presents to the emergency department with symptoms consistent with a stroke. A severe headache develops, followed by confusion and hemiparesis on his left side. He has a long-standing history of hypertension treated with an angiotensin-converting–enzyme (ACE) inhibitor. On examination, he appears euvolemic, with an elevated blood pressure of 150/100 mm Hg and normal serum electrolyte levels. What type and rate of maintenance intravenous fluid would you administer while the patient is receiving nothing by mouth before evaluation and management of a possible stroke?

Answer: An appropriate fluid would be 5% dextrose in a solution of 0.9% saline at a rate of 100 ml per hour. This patient appears to have an acute intracranial process suggestive of a stroke. He is at risk for increased intracranial pressure and cerebral edema. Patients with CNS processes are at high risk for hyponatremia due to the syndrome of inappropriate antidiuresis or cerebral salt wasting. In addition, hyponatremia can have extremely serious consequences in patients with CNS disease, since a small decrease in the serum sodium concentration could result in cytotoxic cerebral edema, thus aggravating vasogenic cerebral edema, which probably is already present.[75] Administration of 0.9% saline would help to prevent the development of hyponatremia, but the patient's electrolyte levels would need to be monitored closely, since the plasma sodium concentration can decrease in patients with CNS disease who receive 0.9% saline.[72] The addition of 3% saline may be necessary to maintain a serum sodium concentration above 140 mmol per liter.

Box 3. Case 3.

Case 3 illustrates maintenance therapy in a patient with congestive heart failure.

An 87-year-old man who weighs 70 kg and who has a left-lower-lobe pneumonia is admitted to the hospital from a nursing home. He has a history of myocardial infarctions and well-controlled congestive heart failure managed with an ACE inhibitor, a beta-blocker, a thiazide diuretic, and a sodium-restricted diet. He received 500 ml of 0.9% saline during transport to the hospital. His vital signs are stable, and there is no evidence of pulmonary congestion or peripheral edema on examination. Electrolyte levels are remarkable for a serum sodium concentration of 134 mmol per liter, potassium 3.2 mmol per liter, total carbon dioxide 31 mmol per liter, and creatinine 1.2 mg per deciliter (106 μmol per liter). Intravenous antibiotics are initiated. He is weak and has tachypnea and clinically significant coughing. There is a concern that he is too ill to be able to drink sufficient fluids. What type and rate of maintenance intravenous fluid would you administer?

Answer: An appropriate fluid would be 5% dextrose in a solution of 0.9% saline plus 20 mmol potassium chloride per liter at a rate of 60 ml per hour. This patient is at risk for both fluid overload and hyponatremia due to congestive heart failure.[76] Therefore, the rate of intravenous fluids should be restricted. A rate of 60 ml per hour or approximately 1.5 liters per day is probably adequate to maintain good peripheral perfusion without causing fluid overload. This patient has a low serum sodium concentration at 134 mmol per liter, so hypotonic fluids should not be administered. Recent data suggest that sodium supplementation may be beneficial in patients with heart failure.[77] Potassium should be added to the intravenous fluids, since the patient has hypokalemia, probably from the thiazide diuretic and poor nutrition. In this patient, the volume of intravenous medications needs to be accounted for, since it could contribute to both fluid overload and hyponatremia.

recommendations regarding fluid have historically been opinion-based. It has now become clear that the administration of hypotonic maintenance fluids (sodium concentration, <130 mmol per liter) is associated with the development of hospital-acquired hyponatremia as well as with deaths or permanent neurologic impairment from hyponatremic encephalopathy.

Acutely ill patients have multiple stimuli for AVP that place them at risk for the development of hyponatremia. Numerous prospective studies involving children have shown that isotonic fluids are safe and effective in preventing hospital-acquired hyponatremia. Acutely ill patients can have a variety of conditions that can alter body-water homeostasis, so both the rate and the

composition of intravenous fluid should be prescribed carefully. Isotonic fluids are the most appropriate maintenance fluid in the vast majority of situations. In Box 1, Box 2, and Box 3, we provide three practical cases regarding the most appropriate rate and composition of maintenance intravenous fluid.

Data from studies to determine whether balanced solutions are superior to saline solutions for maintenance fluids and to determine the most appropriate potassium concentration in fluids are lacking. A solid evidence base from which consensus guidelines for fluid therapy could be built is also needed to better standardize fluid management.

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