7 Fluids, Electrolytes, and Acid–Base Disorders

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CONTENTS

Background . . . 99
Fluid Compartments . . . 99
Fluid Balance . . . 100
Fluid and Electrolyte Disorders . . . 101
General Principles for the Management of Electrolyte Disorders . . . 102
Sodium . . . 102
Hyponatremia . . . 102
Hypernatremia . . . 104
Potassium . . . 104
Hypokalemia . . . 106
Hyperkalemia . . . 107
Magnesium . . . 109
Hypomagnesemia . . . 109
Hypermagnesemia . . . 110
Calcium . . . 111
Hypocalcemia . . . 111
Hypercalcemia . . . 112
Phosphorus . . . 112
Hypophosphatemia . . . 112
Hyperphosphatemia . . . 114
Acid–Base Balance . . . 114
Acid–Base Physiology . . . 114
Definitions . . . 114
Regulation of Hydrogen Ion Concentration . . . 114
Chemical Buffers . . . 114
Lungs . . . 115
Kidneys . . . 115
Normal Blood Gas Values . . . 115
Analysis of Acid–Base Disorders . . . 115
Acid–Base Disorders . . . 115
Respiratory Acidosis . . . 115
Respiratory Alkalosis . . . 116
Metabolic Acidosis . . . 116
Normal Anion-Gap Acidosis (Hyperchloremic Acidosis) . . . 117
High Anion-Gap Acidosis . . . 118
Metabolic Alkalosis . . . 118
Saline-Responsive Metabolic Alkalosis (Urine Chloride <10 mEq per Liter) . . . 118
Saline-Unresponsive Metabolic Alkalosis (Urine Chloride >10 mEq per Liter) . . . 118
Mixed Acid-Base Disorders . . . 118
References . . . 118

ASPEN_CH07.qxd 7/1/12 7:01 PM Page 99

Objectives

1. Describe factors that influence fluid movement between the intracellular and extracellular fluid compartments.
2. Calculate replacement and maintenance fluid requirements for various patient populations.
3. Recommend appropriate treatment for common electrolyte abnormalities.
4. Evaluate and treat acid–base disorders based on the clinical presentation and accompanying laboratory data.

Testing Your Knowledge Questions

1. The administration of 1 L of 0.9% sodium chloride to a normonatremic patient will increase the intravascular and interstitial fluid compartments by:
   A. 1000 mL and 0 mL, respectively
   B. 0 mL and 1000 mL, respectively
   C. 750 mL and 250 mL, respectively
   D. 250 mL and 750 mL, respectively
2. Assuming the same weight and serum sodium concentration, which of the following patients has the greatest free water deficit?
   A. A 35-year-old male
   B. A 75-year-old male
   C. A 35-year-old female
   D. A 75-year-old female
3. Which of the following electrolyte derangements is commonly seen in a patient with a high output nasogastric tube?
   A. Hyperchloremia and hyperkalemia
   B. Hyperchloremia and hypokalemia
   C. Hypochloremia and hyperkalemia
   D. Hypochloremia and hypokalemia
4. A patient with severe intractable nausea and vomiting is at risk for which of the following acid–base disorders?
   A. Hyperchloremic metabolic alkalosis
   B. Hyperchloremic metabolic acidosis
   C. Hypochloremic metabolic alkalosis
   D. Hypochloremic metabolic acidosis

Testing Your Knowledge Answers

1. The correct answer is **D**. 0.9% sodium chloride (154 mEq per liter) is isotonic and, therefore, does not contribute to an osmotic gradient. Isotonic saline enters and remains in the extracellular fluid (ECF). Thus, administering 1 L of 0.9% sodium chloride expands the ECF by 1 L. The intravascular volume accounts for 25% of the ECF and will be expanded by 250 mL. The remaining 750 mL will be distributed to the interstitial fluid compartment.
2. The correct answer is **A**. Free water deficit is calculated as follows:

$$\text{Water deficit (L)} = 0.5 \times \text{body weight (kg)} \times \left(\frac{\text{Plasma sodium (mEq/L)}}{140\ \text{mEq/L}} - 1\right)$$

   Given the same body weight and serum sodium concentration, the only variable is the percent of total body water (TBW). The percent of TBW increases as the proportion of lean body mass to adipose tissue increases. In general, the percent of TBW decreases with age and with female gender due to an increase in the proportion of body fat compared to lean body mass. Younger males would be expected to have the highest proportion of lean body mass, the highest percentage of TBW, and therefore the largest free water deficit.
3. The correct answer is **D**. Gastric fluids are composed of hydrochloric acid, sodium chloride, and potassium chloride. Patients who require continuous or intermittent nasogastric suction may lose large amounts of gastric fluids and the electrolytes contained within these fluids. As a result, patients may develop electrolyte derangements such as hypochloremia and hypokalemia.
4. The correct answer is **C**. Gastric fluids contain approximately 130 mEq per liter of chloride and are very acidic with a pH of 1 to 2. Loss of large amounts of gastric fluids via vomiting, especially for a prolonged period of time, can result in a hypochloremic metabolic alkalosis.

Background

Body fluids differ with regard to their distribution and the substances dissolved within them. These substances include electrolytes and nonelectrolytes, such as glucose and proteins. Despite variations in daily intake, fluid and electrolyte balance is maintained through a complex system of regulatory mechanisms to maintain an environment conducive to normal cell function. Cell function is also highly dependent on acid–base homeostasis because nearly all biochemical reactions are influenced by hydrogen ion concentration. In practice, disruption of fluid, electrolyte, and acid–base homeostasis is common, the results of which can have a profound physiological impact on many organ systems. This chapter discusses normal body requirements, the distribution and homeostasis of water and electrolytes, as well as the evaluation and treatment of common fluid, electrolyte, and acid–base disorders.

Fluid Compartments

Water, the most abundant substance in the body, constitutes approximately 50% to 60% of body weight. Total body water (TBW) is a function not only of weight, age, and sex, but also of the relative amount of body fat. Of all body tissues, adipose tissue is least hydrated. Thus, individuals with more body fat have proportionally less TBW content.[1]

Total body water is distributed among three main compartments: the intracellular, the extracellular, and the transcellular fluid compartments. Approximately two thirds of TBW is contained in the intracellular fluid (ICF) and the remaining one third is in the extracellular fluid (ECF). The transcellular fluid compartment accounts for only about 3% of TBW and includes specialized fluids such as cerebrospinal fluid, the aqueous humor of the eye, and secretions of the gastrointestinal tract. Of all fluid compartments, the ECF is the most clinically important, because it contains the intravascular and interstitial spaces.[2]

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ASPEN_CH07.qxd 7/1/12 7:01 PM Page 100

Osmotic pressure, defined as the pressure required to maintain equilibrium with no net movement of solvent, is of prime importance in determining the distribution of water between the extracellular and intracellular spaces. Each compartment contains one major osmotically active solute that ultimately determines its osmotic pressure. Sodium is the dominant extracellular osmole, which acts to hold water in the extracellular space, whereas potassium is the primary intracellular osmole and acts to hold water within the cells. Activity of cellular sodium-potassium-adenosine triphosphatase (Na^+-K^+-ATPase) pumps allows for the maintenance of these unique solute compositions of the ECF and ICF and plays a key role in the regulation of cell volume.[1]

To better illustrate the dynamics of water distribution between the ICF and ECF, consider the exogenous administration of intravenous fluids. If 1 L of 5% dextrose in water (solute-free water) is infused, the dextrose is metabolized, and the water distributes proportionately to all fluid compartments. That is, two thirds (667 mL) of it will distribute into the ICF and one third (333 mL) will distribute into the ECF. Of the one third distributed into the ECF, 25% (85 mL) will remain in the intravascular space. This is in contrast to the administration of 1 L of 0.9% sodium chloride (isotonic saline), which is distributed completely to the ECF where one quarter (250 mL) will remain in the intravascular space. Alternatively, the addition of hypertonic fluid (eg, 3% NaCl) to the ECF increases its tonicity, establishing an osmotic gradient that results in the movement of water out of cells and into the ECF until osmotic equilibrium is attained. The osmolalities of both compartments will be increased—that of the ECF due to the addition of NaCl and that of the ICF due to water loss. The volume change will be proportional to the degree of increase in ECF osmolality (Fig. 7.1).[3]

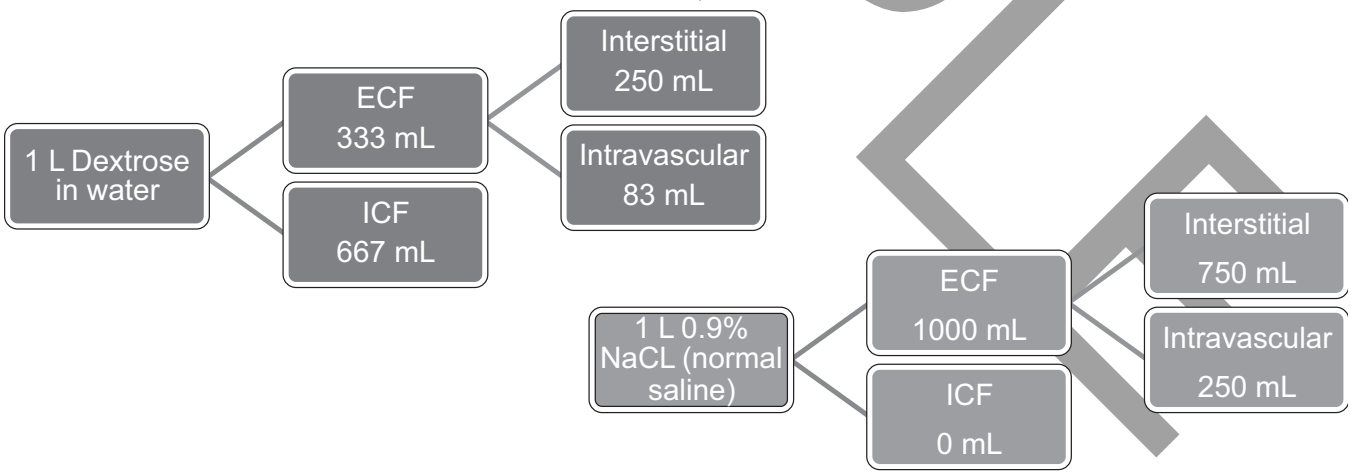
Although osmotic forces determine the distribution of water between the intracellular and extracellular fluid space, the plasma oncotic and hydrostatic pressure govern the movement of fluid between the plasma and interstitial fluid. These forces are generally balanced such that despite large fluid exchanges between compartments, compartment sizes are maintained in a steady state. Disruption in oncotic and/or hydrostatic pressure results in a net flow of fluid from one compartment to another. When these disruptions favor a plasma-to-interstitial fluid shift, third spacing occurs. Third spacing is the accumulation of excess fluid in the interstices (edema) or in the potential fluid spaces (effusion).[4] Although the fluid will be absorbed back into the extracellular compartment over a period of days to weeks, the acute reduction in blood volume, if not replaced, can lead to severe volume depletion.

This phenomenon is common during critical illness when capillary permeability increases, resulting in the leakage of albumin from the intravascular to the interstitial space. This reduces the plasma oncotic pressure and, thus, favors the movement of fluid from the intravascular to the interstitial space. Specific examples of this phenomenon include intestinal obstruction, severe pancreatitis, crush injuries, bleeding, peritonitis, and obstruction of a major venous system.

Fluid Balance

Fluid gains (input) should be in balance with fluid losses (output) over a period of several days. On average, a healthy adult

FIGURE 7-1 Water Distribution to the Extracellular Fluid and Intracellular Fluid and Composition of Commonly Used Intravenous Fluids



Solution	Dextrose (g/L)	[Na+] (mEq/L)	[Cl−] (mEq/L)	Tonicity	Free Water/L
D5W (5% dextrose)	50	0	0	Hypotonic	1000 mL
0.45% NaCl (½ normal saline)	0	77	77	Hypotonic	500 mL
0.9% NaCl (normal saline)	0	154	154	Isotonic	0 mL
3% NaCl (hypertonic saline)	0	513	513	Hypertonic	−2331 mL
Lactated Ringer's	0	130	109	Isotonic	0 mL

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ASPEN_CH07.qxd 7/1/12 7:01 PM Page 101

	Weight (kg)	Na+ (mEq/L)	K+ (mEq/L)	Cl− (mEq/L)	HCO_3^- (mEq/L)	BUN (mg/dL)	Creatinine (mg/dL)	Glucose (mg/dL)	Daily Fluid Balance (L)
Day 1	66	134	4	101	26	11	1.1	148	+2.5
Day 3	69	128	3.8	109	32	8	0.9	124	+4
Day 5	62	138	3.5	99	27	15	1.2	137	−6

will require 30 to 40 mL per kilogram per day of fluid to maintain this balance.[5,6] Water intake is derived primarily from the diet (including that generated from the oxidation of carbohydrates, proteins, and fats), whereas various sources of water loss contribute to total fluid output. In most cases, sensible losses from the gastrointestinal tract and kidneys account for the majority of fluid loss, although insensible losses from the lungs and skin can contribute up to 1 L per day.[1] See Practice Scenario 7-1 for a discussion of maintenance fluids in a common clinical condition.

Practice Scenario 7-1

Question: How would you manage maintenance fluids for a patient with heart failure?

Scenario: RA is a 65-year-old male (75 kg; IBW 66 kg) with a past medical history significant for heart failure (HF) and diabetes admitted to your hospital for HF exacerbation. A physical exam reveals jugular venous distention, rales, and 3+ pitting edema in bilateral lower extremities. RA is currently receiving oxygen therapy at 8 L per minute via a nasal cannula and is unable to tolerate an oral diet. 0.9% sodium chloride was initiated at 125 mL per hour. On hospital day 3, RA's oxygen requirements increased necessitating noninvasive positive pressure ventilation and transfer to the intensive care unit (ICU).

Intervention: Upon transfer to the ICU, the intensivist started a furosemide continuous infusion and changed IV fluids to 0.45% sodium chloride at 10 mL per hour to maintain IV access.

Answer: Patients who present with fluid overload secondary to HF exacerbations cannot tolerate normal maintenance fluid requirements. For patients with HF, fluid intake should be between 1.4 and 1.9 L per 24 hours, depending on clinical symptoms (ie, edema, fatigue, shortness of breath). Additionally, sodium should be restricted to less than 2000 mg per day.[7,8] Maintenance fluid requirements for a healthy 75 kg male would be 30–40 mL/kg/day (2250 to 3000 mL per day). Because RA has a history of HF and was admitted with fluid overload and shortness of breath, 3 L per day of maintenance IV fluids contributed to further respiratory decompensation, requiring aggressive diuresis and ICU transfer. The restriction of IV fluids and sodium along with diuresis resulted in decreased oxygen requirements and improvement in other clinical symptoms associated with fluid overload.

Rationale: HF patients with evidence of significant fluid overload should initially be treated with loop diuretics and sodium and fluid restriction. Therapy for hospitalized patients with decompensated HF should begin as soon as possible because early interventions have been associated with better outcomes.[9,10] After admission to the hospital, patients should be carefully monitored in accordance with the severity of their symptoms and the results of initial findings on the physical examination and laboratory assessment.

Plasma osmolality (water balance) is maintained within the normal range of 275 to 290 mOsm per kilogram. This is essential because variations of only 1% to 2% initiate mechanisms to return the plasma osmolality to normal.[1] Two mechanisms regulate water balance: (1) the thirst sensation, and (2) control of renal water excretion by antidiuretic hormone (ADH). The body responds to a water load by suppressing ADH secretion, resulting in decreased collecting tubule water reabsorption and excretion of excess water. The correction of a water deficit requires the intake and retention of exogenous water achieved by increases in thirst and ADH release. Efficiency of this regulatory system is incomplete if any renal impairment or abnormality in the thirst mechanism exists.

Fluid And Electrolyte Disorders

Disorders of fluid balance can be classified as disturbances of volume, concentration, or composition. These disturbances often occur simultaneously in clinical practice. A gain or loss of fluid (ie, water and solute) will alter extracellular fluid volume as determined by physical findings. Such a disturbance is referred to as volume overload or hypervolemia (gain) or conversely as volume depletion or hypovolemia (loss). The gain or loss of water alone is referred to as overhydration or dehydration, respectively, and is recognized by a change in serum sodium concentration and plasma osmolality.[2] Volume depletion describes the loss of sodium and water from the extracellular space (intravascular and interstitial fluid) that occurs after gastrointestinal hemorrhage, vomiting, diarrhea, and diuresis.[11] A disturbance of composition refers to a gain or loss of potassium, magnesium, calcium, phosphate, chloride, bicarbonate, or hydrogen ions.

Knowledge of the composition of specific body fluids is useful in the management of fluid and electrolyte disorders because many causes of water loss also result in significant losses of electrolytes. Table 7-1 shows the volume of fluid secreted and its electrolyte content throughout the gastrointestinal (GI) tract.[12] Abnormalities in renal excretion and excessive losses from the GI tract (ie, vomiting, nasogastric suctioning, diarrhea) are often cited as primary contributors to electrolyte imbalances. Identifying the etiology of the electrolyte imbalance is essential to providing safe and effective treatment.

The therapeutic approach to fluid and electrolyte disorders also requires clinicians to determine the time frame in which the abnormality occurred. Generally, the development of an acute abnormality (<48 hours) is associated with symptoms

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