The author presents a review of the distribution of body fluids in the adult patient, and discusses the major electrolytes and their impact on the patient. The caloric needs of the adult surgical patient are also presented.

It is commonly recognized that Homo sapiens are predominantly composed of water, with a complex distribution of substances within that water environment, all contained in a sack of skin. This article will discuss the distribution of the body's water in its various compartments as well as some of the many substances found in these compartments.

Some scientists have proposed that the fluid environment is a natural carry-over of the aquatic environment from which man evolved. Others propose that man is the result of divine engineering, originating as he is today. Whatever viewpoint is taken, as nurse anesthetists, we have a responsibility for understanding as well as maintaining our patient's physiology for that short period of his life while he is under our care.

Content and distribution of body fluid and electrolytes

The total body water of the adult is distributed into intracellular and extracellular compartments which account for approximately 40% and 20% of the lean body weight, respectively, in the healthy 70 kg adult male. As can be seen from those figures, the total body water of 42 L is divided into 28 L of intracellular and 14 L of extracellular fluid. Normal variations of these figures may be important to consider and are as follows: Females have an average body water content of 55% of lean weight. As the person ages to approximately 60 years, the total body water of the male decreases to 50% of body weight and in females, it decreases to 45%. By contrast, the newborn is 75-80% water which also declines as the child ages.

The distribution of electrolytes is such as to concentrate sodium and chloride ions in the extracellular fluid while potassium, proteins, and phosphates are concentrated in the intracellular fluid. One exception to this electrolyte distribution occurs within the red blood cell where a higher concentration of sodium exists than in other cells. There is a higher concentration of ions in the intracellular fluid. Because of this, the extracellular osmotic activity is greater since it depends upon the number of osmotically active particles in solution (milliosmoles) and not on the chemical combining capacity reflected as milliequivalents (mEq) per liter.

We know that the body fluids are isotonic and that water passes freely between the various body compartments to maintain this tonicity as close to normal as possible. The influences of ingestion of hypo-and hyper-tonic fluids will be discussed later in this article.
We are also aware that the pH of arterial blood is 7.4 while that of venous blood and interstitial fluid is 7.35 because of a higher concentration of carbon dioxide (CO₂). The intracellular pH varies from 6.0-7.4 in different cells of the body. One factor responsible for this variation is the degree of metabolic activity of the cell which alters the liberation of CO₂ and therefore the pH. In addition, if blood flow through the tissue is slow, there would naturally be a greater accumulation of CO₂ again decreasing the pH. In the healthy person, the kidneys, lungs and hemoglobin operate to maintain normal acid-base balance.

Caloric requirements. There is a great variation in the daily caloric requirements of individuals. The minimum energy expended by a 70 kg adult male is approximately 1 calorie/kg/hr in a sleep state or 1680 calories/day. The average postoperative patient requires 2500 calories per day and only a small amount of this can be supplied by 5% glucose solutions because of the excessive fluid volume which this would require. The infusion of hyper- or hypo-tonic solutions requires a short time for equilibration with intracellular tonicity to occur, either by liberating or taking up intracellular water.

Perioperative fluid and electrolyte management

There are several pathologic states associated with fluid and electrolyte disturbances in the surgical patient. One must first consider the basic fluid maintenance needs of the 70 kg adult. Since he typically loses 2500 ml per day, we must replace this fluid in the operative day. This can readily be accomplished by administering fluid at the rate of approximately 100 ml/hr. In 1956, Holliday and Segar developed a formula for maintenance fluid replacement which is useful in persons of all ages. It is based on the needs for water computed as a function of energy metabolism. The daily recommended amounts calculated for normal maintenance for the typical 70 kg male are given in Table I.

Using these calculations, the hourly dose would be 104 ml/hr. The patient who comes to surgery at 7 a.m., having been NPO since midnight, has a fluid deficit of 725 ml. Half of this deficit should be replaced during the first hour in surgery, with the remaining half divided during the second and third hour of surgery. This is in addition to replacing the 104 ml of hourly required fluid.

Intraoperative fluid management must consist of not only maintenance replacement, it must also include replacement of fluids lost through evaporation, suction, drainage and blood loss. Evaporative losses in patients with abdominal incisions have been estimated by numerous authors. The amount of loss will obviously vary with the extent of surgery. It varies from an additional 2 ml/kg/hr for minor operations such as hernia repairs to 8-10 ml/kg/hr for thoraco-abdominal procedures. This, of course, is in addition to maintenance requirements and other fluid losses.

Replacement must begin before sympathetic compensatory mechanisms begin to avoid vasoconstriction. Along with evaporative losses, fluids may be lost in surgical packs, nasogastric tubes or cutaneous losses from hyperthermia. According to Jacobson this can amount to another 3-4 L per day in the 70 kg patient. Evaporation is a cooling process and during abdominal surgery, the temperature of an exposed bowel may decrease 3-5° C. It is also important that the body heat be conserved as well as the body fluid. Insensible water loss is greater just after surgery, presumably reflecting "third space" loss.

Special attention must be given to fluid replacement in the burned patient. The Brooke formula recommends administration of lactated Ringer's solution as follows: 2 ml/kg/% burn in the adult and 3 ml/kg/% burn in the child. One-half the calculated volume is given the first eight hours and one-fourth during each of the next two 8-hour periods. In the second 24 hours, any plasma deficit is replaced with colloid-containing fluid at a rate of 0.4 ml/kg/% burn. The Parkland formula recommends lactated Ringer's solution at a rate of 4 ml/kg for each 1% estimated body burn during the first 24 hours.

Volume excesses are usually iatrogenic and may be evidenced in patients with renal or cardiac insufficiency, manifested as pulmonary edema from circulatory overload. For this reason it is suggested that large volume replacement be accompanied by monitoring of urinary output, specific gravity, and central venous pressure (CVP) or Swan-Ganz™

As a result of surgery a number of changes occur in the distribution of body fluids. Most of

<table>
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<td>Normal daily maintenance fluid replacement</td>
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<td>100 ml/kg of body weight for the first 10 kg = 1000 ml</td>
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<td>50 ml/kg of body weight for the second 10 kg = 500 ml</td>
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<td>20 ml/kg of body weight for the remaining = 1000 ml</td>
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<td>Total = 2500 ml</td>
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the gains and losses of body fluids occur from the extracellular fluid compartment. If the gain or loss is isotonic, there is only volume change. If the gain or loss is water alone, however, there is also a change in the concentration of osmotically active particles, the most common being sodium. For this reason most clinicians strongly feel that there is no place in the resuscitative regimen for 5% dextrose in water. Recent losses or additions to the extracellular fluid will not change the composition of that fluid.

Some common volume deficits involving extracellular fluid during surgery as described by McAslan\(^5\) include: (1) external losses such as hemorrhage, exudate, vomiting, nasogastric suction, diarrhea and fistulous drainage; and (2) internal losses from sequestration in burns, surgical injury, peritonitis and ascites.

During surgery third space losses, which consist of additional blood loss into surgical areas, extracellular transudate into the walls and lumen of the bowel, peritoneal and retroperitoneal spaces, all require replacement. Often electrolyte containing solutions, administered at a rate of 1/2-1 L/hr to a maximum of 3 L in four hours during extensive surgical involvement, will compensate for these losses. Since capillary leakage increases during surgical procedures, the onotic pressure will decrease and the administration of colloid solutions will be ineffective until capillary leakage stops.\(^6\)

Postoperative urinary output will increase to mobilize large volumes provided that infusions are begun before ADH (vasopressin) activity is stimulated.

Burn patients need some special considerations in fluid management which the anesthetist should keep in mind. Edema fluid accumulates from the intravascular compartment to the greatest extent during the first 6-8 hours post-injury and continues for 36 hours. The body compensates for this intravascular fluid loss by vasoconstriction, hemocentration, red cell and platelet aggregation and increased hydrostatic pressure. The overall effect is to increase the work of the heart. Functional capillary integrity returns during the second 24 hours postburn. Until this time, the hematocrit is unresponsive to fluid therapy and as such is a poor guide to resuscitation.

Intravenous fluid therapy is usually unnecessary in adults with less than 20% body burns or in children with less than 10% body burns, that is, unless signs of hypovolemia are present. Using either the Brooke or Parkland formula, administer 2-4 ml/kg/% burn lactated Ringer's solution each day. Whole blood and albumin are administered after capillary permeability is restored to prevent unnecessary expense to the patient.

During surgery for tangential excisions and debridement of burned patients, packed red cells are administered throughout surgery as needed to keep up with blood loss. Fresh frozen plasma and/or albumin are usually withheld until capillary oozing has ceased. Postoperatively, packed cells are given to maintain the hematocrit between 30-35%.

### Content and distribution of electrolytes

In addition to water replacement, we must consider the electrolyte needs of the surgical patient.

**Sodium.** Sodium balance can be markedly varied by improper perioperative fluid therapy. The normal balance of 142 mEq/L can be maintained by the daily intake of 50-90 mEq. Although small amounts are normally lost through the skin and intestines, a balance is maintained by renal excretion of any excesses. The sodium concentration indicates the osmolality or tonicity of body fluids. If water is administered faster than the kidneys can excrete it, the extracellular sodium concentration will decrease. This can occur if large quantities of glucose and water are administered or if large quantities of water are absorbed from the bladder. Water intoxication can be reflected by increased blood pressure, bradycardia and increased intracranial pressure manifested as drowsiness, convolution and coma.

Hypernatremia may occur following the rapid infusion of salt solutions or decreased water intake resulting in dehydration, or from excessive sweating or diabetes insipidus from pituitary tumors, renal tubular disease, gastrointestinal hemorrhage or excessive sodium administration. Cerebral complications appear when serum sodium concentrations exceed 165 mEq/L and cell function is impaired when intracellular fluid loss exceeds 15%. The appropriate water deficit can be calculated, as suggested by McAslan, by comparing measured versus ideal sodium.\(^2\) One-third of the calculated deficit should be replaced during the first four hours using fluids with a sodium concentration of 30-75 mEq/L, for example, 1/2 normal saline and the remainder given as 5% dextrose or 1/5 normal saline over a period of 36-48 hours. Normal water requirements for maintenance must also be administered. If the anesthetist is treating hypernatremia, he or she must remember not to administer large quantities of 5% dextrose in water, as this can lead to water intoxication.
**Potassium.** Potassium is an important intracellular ion because it controls osmotic pressure, activates enzymatic reactions, helps regulate acid-base balance, influences kidney function and maintains neuromuscular excitability. Normal serum potassium levels are 4.5 mEq/L. The kidneys are primary organs of potassium excretion, causing a daily loss of 8 mEq in the urine. Another 11 mEq per day are lost in the feces. Although the majority of total body potassium is normally found inside the cell, extracellular potassium can rise in response to severe injury, surgical stress, acidosis or catabolic diseases. In the presence of renal dysfunction, the serum levels of potassium can rise to above 6 mEq/L.

Potassium intoxication is reflected by a serum value above 5.4 mEq/L and may be caused by: (a) diminished renal excretion; (b) increased catabolism of endogenous protein; and (c) rapid and/or excessive administration.

Hyperkalemia is manifested by confusion, increased gastric motility, bradycardia, and ECG changes which include tenting or peaking of the T wave, depression of S-T segment, increased duration of QRS complex to greater than 0.1 seconds and an increased PR interval to more than 0.2 seconds. Emergency treatment consists of administering solutions containing 80 mEq of sodium lactate intravenously (IV) to increase the pH and force potassium ions back into the cell, administering 100 ml of 50% dextrose in water to stimulate glycogen synthesis and giving 100 ml of calcium gluconate to counteract the myocardial effects of hyperkalemia. Insulin is also useful in forcing potassium back into the cell but it may cause hypoglycemia if glucose is not administered.

Potassium deficiency can occur in aldosteronism, renal disease, congestive heart failure, prolonged diuretic therapy, or marked losses of gastrointestinal fluids. Although acute losses can generally be tolerated, prolonged deficits cause heart and neuromuscular changes. Signs and symptoms of hypokalemia include:

1. Decreased muscle strength.
2. Prolonged Q-T interval.
3. Flattening of T wave.
4. S-T segment depression.
5. P wave inversion.

Hypokalemia can be treated by IV infusion of potassium. The infusion rate should be no faster than 15-20 mEq/L per hour given from a solution with a concentration no higher than 40-80 mEq/L of fluid. The patient receiving parenteral potassium should have ECG monitoring for signs of hyperkalemia.

**Calcium.** Although sodium and potassium imbalances are most commonly seen in the perioperative state, hypercalcemia may be seen in the patient with hyperparathyroidism or carcinoma with bone metastasis. The signs and symptoms of hypercalcemia include: (1) fatigue, lassitude, stupor or coma; (2) headaches, pain in back and extremities; and (3) anorexia, nausea, vomiting, weight loss.

Treating hypercalcemia requires the rapid administration of saline. The kidneys reabsorb sodium and excrete calcium. If this is not sufficient, diuretics which act on the loop of Henle such as furosemide (Lasix®) and ethacrynic acid (Edecrin®) are useful. Thiazide diuretics will actually inhibit calcium excretion and should not be used. Steroids and mithramycin (Mithracin®) are also useful.

Hypocalcemia is generally rare but may result from hypoparathyroidism, vitamin D deficiency, magnesium deficiency, acute pancreatitis or massive soft tissue infections. Signs and symptoms of hypocalcemia include:

1. Circumoral numbness and tingling.
2. Hypoactivity of deep tendon reflexes (DTRs) and positive Chvostek’s sign.
3. Tingling of fingers and toes and carpopedal spasms.
4. Abdominal cramps.
5. Tetany and convulsions.

Hypocalcemia can be treated by the administration of IV calcium. Care should be taken to avoid extravasation of solution since it is extremely irritating.

**Magnesium.** Magnesium is often called the forgotten electrolyte. Deficiencies are rarely encountered since adequate supplies are part of the common diet. When there is impairment of absorption or rapid excretion, hypomagnesemia may occur. It may occur with: (1) malabsorption syndromes; (2) chronic diarrhea; (3) bowel resection; (4) alcoholism; (5) hypercalcemia; (6) diabetic acidosis; and (7) diuretic therapy.

Signs and symptoms of hypomagnesemia are:

1. Hyperactivity of deep tendon reflexes (DTRs).
3. Tetany.
4. Delirium and convulsions.

These symptoms may be seen with normal magnesium serum levels of 1.5-2.5 mEq/L. Hypomagnesemia can be treated by parenteral mag-
nesium sulfate 80 mEq added to 1 L of IV fluid and given over a 24 hour period.

Hypermagnesemia may be found in patients unable to excrete magnesium such as those with chronic renal failure or those taking large amounts of magnesium-containing antacids or cathartics. An additional and unique situation in which the anesthetist may encounter a hypermagnesemic patient is in the obstetrical unit when the eclamptic patient has been given magnesium sulfate. Magnesium depresses acetylcholine release at the myoneuronal junction and therefore markedly potentiates the action of muscle relaxants. Signs and symptoms of hypermagnesemia are: flushing, sweating, and weak or absent DTRs. Other symptoms resulting from interference with neuromuscular transmission include hypotension and hypothermia, drowsiness and diminished cardiac function.

*Alterations of pH.* Changes in blood pH greatly affect the movement of electrolytes across the cell membranes. With acidosis, the body attempts to compensate by moving sodium and potassium out of the cell and into the extracellular fluid in exchange for hydrogen ions moving into the intracellular fluid. Additionally, larger than normal amounts of chloride ions move into the red blood cells from the plasma in exchange for bicarbonate ions. This is an exaggeration of the normal chloride shift mechanism which aids in the transport of carbon dioxide out of the body. The kidneys reabsorb more sodium and excrete hydrogen, creating a more acidic urine. Losses of bicarbonate ions via the kidneys will cause acidosis. The loss can occur with diarrhea or in someone who ingests large amounts of alkali. Excessive intake of aspirin can cause metabolic acidosis.

With alkalosis, the body attempts to compensate for increased bicarbonate levels in the extracellular fluid by retaining acid salts, namely carbonic acid. The renal system helps to correct alkalosis by conserving hydrogen ions while excreting large amounts of sodium and potassium ions. Ammonia production slows, aiding the conservation of hydrogen. The result is an alkaline, rather than a slightly acid, urine. Understanding these changes should help us take approximate therapeutic measures to maintain the patient's physiology within normal parameters.

**Caloric requirements of the surgical patient**

Although not within the complete control of the anesthetist, caloric requirements are also a facet of total patient care, and thus, should be understood. As mentioned earlier, the average postoperative patient requires 2500 calories per day intake for plasma protein formation, wound healing and to meet his daily metabolic needs. Since each liter of 5% dextrose only provides approximately 170 calories, it is obvious that attempting to supply the entire caloric needs from this source would result in a vast fluid overload.

Jacobson supplied patients having extensive bowel surgery with 2200-2800 calories per day by IV infusion of a total parenteral nutrition fluid for 5 days after surgery. Recognizing these caloric needs, the anesthetist may be able to provide a part of these calories by the use of a 50% dextrose solution as part of the fluid used in routine resuscitation during surgery. This would require careful monitoring of blood and urine sugar to prevent hyperglycemia. Rich and Wright believe that clinicians generally overestimate the patient's water, sodium, potassium and magnesium needs and underestimate their calcium, nitrogen and caloric needs.7 Burn patients are in a hypermetabolic state and have increased caloric requirements.

**Intravenous solutions.** The question always arises as to which IV solution is best to use for our patients. There is no straightforward answer as there are several factors to be considered by the clinician in each case.

A commonly used solution is 5% dextrose in water.8 This provides little caloric value and has the risk of producing water intoxication. It will promote sodium diuresis in the hypernatreic patient, however, as it is hypotonic. Solutions of dextrose in sodium chloride also promote diuresis and correct excessive fluid loss, however, it can load and aggravate the edema in patients with heart, renal or liver disease. These solutions are isotonic by contrast to the water solutions.

The most commonly used solutions are those which provide a combination of dextrose and lactated Ringer's solution. The dextrose provides some calories depending on its strength and the Ringer's solution contains sodium, chloride, potassium and calcium in concentrations just slightly hypotonic. These solutions are useful in replacing surgical and gastrointestinal losses, as well as losses leading to dehydration. There is no evidence to indicate that there are harmful effects from accumulation of lactate from these solutions.

Hypertonic solutions such as dextran and albumin may be useful in increasing plasma colloid osmotic pressure. However, dextran should be limited to not more than 2000 ml and may cause red cell clumping, thereby interfering with blood type and cross-matching. Albumin is extremely expensive for use as a plasma expander. If active bleeding or capillary leaking occurs, chances are
that the albumin will be lost to the circulation anyway.

If blood replacement is needed, the generally recommended approach is to administer packed red cells reconstituted with normal saline. Coagulation factors and other blood components are administered as specifically needed.

Summary

We have reviewed the basic contents and distribution of body fluids as represented in the normal adult in this article. We have also discussed the major electrolytes of the body and some of the changes associated with pH. The conclusion deals with an outline of the caloric needs of the surgical patient and how they can readily be supplied. A brief discussion of various intravenous solutions available for common use was provided to assist the anesthetist in choosing the best solution for each individual patient.

REFERENCES


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