# Chapter 14

# Electrolytes, Fluids, Acid-Base Analysis, and Transfusion Therapy

**Francis X. Dillon**

*For maximum impact, it is recommended that the case study and questions found on page xxiv are reviewed before reading this chapter.*

## Key Learning Objectives

- Understand the risks and benefits of fluid replacement therapy options
- Know how to calculate a patient's fluid requirements and allowable blood loss
- Learn the types of blood transfusion therapy available and their indications

## Electrolytes and Fluid Compartments

The body is about *60% water* by weight. Water is partitioned in various named compartments in the body (see Table 14.1), including the intracellular and extracellular spaces. Many of the problems patients develop in the perioperative period are a direct result of fluid shifts within the extracellular (*intravascular* → *interstitial*) spaces. These range from peripheral edema, to intravascular hypovolemia and shock, to cellulitis and decubitus ulcers, to pericardial and pleural effusions, to cerebral edema, to the Adult Respiratory Distress Syndrome (ARDS). Fluid shifts predispose patients to serious infections and increased mortality via a number of mechanisms.

Abnormal fluid shifts from the intracellular (40 L) to the extracellular (15 L) compartment and vice versa cause even more dramatic illnesses, some fatal. These include lysis of various cells ranging in function from erythrocytes to neurons, swelling of the brain and spinal cord, and renal failure.

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**Table 14.1 Fluid compartments of the body and their composition.[a]**

| Fluid compartment | Intracellular | (Extracellular)-intravascular | (Extracellular)-interstitial |
|---|---|---|---|
| Synonym | Cytosol | Plasma | Interstitial fluid |
| Routinely assessed during anesthesia? | No | Yes | No |
| Can infuse into with iv catheter and fluids? | No | Yes (usual route to replace blood/fluid) | No |
| Compartment volume (l) | 36 L | 2.4 L | 9.6 L |
| pH | 7.3–7.5 | 7.4 | 7.4 |
| Protein (mosm/l) | 4 | 1.2 | .2 |
| Glucose (mg/dl) | 100 | 100 | 100 |
| Na (meq/l) | 14 | 142 | 139 |
| K(meq/l) | 140 | 4.2 | 4.0 |
| Ca(meq/l) | ‹ 0.0002 | 1.3 | 1.2 |
| Mg (mosm/l) | 020 | 0.8 | 0.7 |
| Cl(meq/l) | 4 | 108 | 108 |
| HCO3(meq/l) | 10 | 24 | 28.3 |
| Lactate (mosm/l) | 1.5 | 1.2 | 1.2 |
| Total mosm/l | 301.2 | 301.8 | 300.8 |
| Corrected mosm/l[b] | 281.0 | 282.0 | 281.0 |
| Total osmotic pressure, mmHg (37°C) | 5,423 | 5,443 | 5,423 |

**[a]Data adapted with permission from: Nguyen M and Kurtz I. Quantitative interrelationship between Gibbs-Donnan equilibrium, osmolality of body fluid compartments, and plasma water sodium concentration. J Appl Physiol 100: 1293–1300, 2006.**
**[b]Corrected for reduced osmotic activity of ions in solution.**

## Oncotic vs. Osmotic Pressures

Fluid in the bloodstream stays in the bloodstream in part because its electrolyte and non-electrolyte solute composition is different from fluid in the interstitial spaces surrounding the vessels. There are two kinds of pressure in body fluids:

- ***osmotic*** pressure: caused by dissolved salts or nonionic small solute molecules
- ***oncotic*** pressure: form of osmotic pressure exerted by proteins in blood plasma; typically pulls water into the circulatory system

Overall, the oncotic plus osmotic pressure gradients tend to favor free water coming back into the intravascular space from the extravascular space. Hydrostatic pressure and the intact semipermeable membranes of the capillaries provide a counterbalancing pressure gradient in the opposite direction. Between these two forces an equilibrium forms.

## Blood Volume and the Fluid Compartments

Blood is made up of parts of two different compartments: both the intracellular compartment (the inner volume of all the circulating blood cells or red blood cell volume (RBCV) whose total is 2 L); and the plasma (the extracellular – intravascular compartment whose total volume is 2.8 L). These two volumes added together make up the blood volume which is 2 + 3 = 5 L (Fig. 14.1).

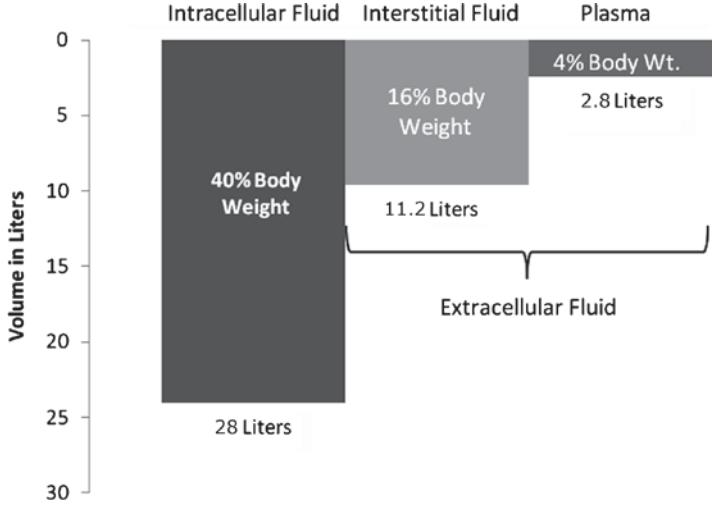


**Figure 14.1 Fluid compartments. (Image Courtesy J. Ehrenfeld, M.D.).**

The entire blood volume circulates in the closed circulatory tree (aorta → arteries → arterioles → capillaries → venules → veins → vena cava) in about one minute (60 s). Therefore on average, the cardiac output is 5 L per minute. Because the circulatory system, the heart, and the pulmonary circulation are closed and blood is incompressible, the sum total flow of all the bloodstream fluid going around the circulatory tree exactly equals the amount going through the heart.

Anesthesiologists are able to exert some control over the solute components and sizes of the fluid compartments by infusing fluids intravenously (into the extracellular – intravascular space). The goal is to maintain the compositions, pressures, and volumes of *all the various fluid compartments* by the proper choice of IV fluids.

Anesthesiologists also transfuse blood products intravenously to replace cells and fluids lost during procedures or as a result of trauma or illness. Transfusing blood products adds volume to both the intracellular space (i.e., the interior volume of red blood cells and platelets) and the extracellular– intravascular space (the non-cellular volume of water, electrolytes, and plasma proteins in plasma). Transfusion will be covered in more detail later in this chapter.

Physicians try to replace intravascular fluids with solutions that have the right tonicity, osmolality, oncotic pressure, viscosity, and cellular composition (among other characteristics) so that they tend to stay intravascular. In doing so, we are trying to accomplish several things:

1. Support preload of the heart, and therefore blood pressure and body perfusion
2. Avoid excessive expansion of interstitial space (edema) and the problems it causes
3. Allow some interstitial fluid to be transported back into the intravascular space (by osmotic or oncotic forces)
4. Avoid perturbing the intracellular space, in particular neurons and other cells for which swelling can be catastrophic

## Patient Evaluation: Fluid Management

The first step in evaluating a patient in need of fluid management is to look at several clinical indicators of intravascular volume status (see Table 14.2). Evaluation and replacement of fluid status is an ongoing process. It is safe to say that after management of the anesthetic depth and control of oxygenation and ventilation, fluid management is the next most important task the anesthesiologist has.

**Table 14.2 Clinical variables used to assess intravascular volume status during anesthesia.**

| Variable | Skin turgor[a] | Neck veins | Systolic Blood Pressure[b] | Variability of blood pressure with respiration[j] | Central venous pressure (CVP)[c] | Urine output (UO)[d] | Heart rate (HR)[e] | Hypotension with anesthesia esp. volatile[f] | Orthostasis[g] | Base excess (BE)[h, i] Or ($HCO_3$) meq/l |
|---|---|---|---|---|---|---|---|---|---|---|
| Hypovolemic | Loose | Flat | Low | High | Less than 8 | Low | High | Likely | High | Less than -2 (or less than 22) |
| Euvolemic | Normal | Pulsatile | Normal | Normal | 8–12 | Normal (0.5–1 ml/kg/h) | Normal | Normal | Normal | [–2 to +2](22–30) |
| Hypervolemic | Puffy | Bulging, distended | Normal to High | Low | Greater than 12 | High | Low | Unlikely | Low | [–2 to +2](22–30) |

[a]Patients with low oncotic pressure (from low serum albumin, etc.) or patients who have been given considerable crystalloid, will be puffy yet may still be hypovolemic in the intravascular space and thus prone to hypotension.
[b]Many patients do not show higher blood pressures if hypervolemic. Also, hypertensive patients may still be hypovolemic.
[c]Requires central venous line access. Values noted are approximate; follow trends in CVP rather than absolute values.
[d]This is affected by many other factors besides volume: ADH secretion, diuretics, intrinsic renal function, etc.
[e]HR variability with volume status is best seen in young healthy awake patients. It is not well seen in elderly, deeply anesthetized or beta-blocked or calcium-channel blocked patients. Nor is it seen in patients with intrinsic nodal or conduction system disease.
[f]Hypovolemic patients become hypotensive with even small amounts or concentrations of anesthetics.
[g]Tilting the patient's body or trunk "head up" when initially supine will result in hypotension if hypovolemic; less so if hypervolemic.
[h]Base excess or bicarbonate ($HCO_3$–) measurements if acidotic (less than –2 (BE) or less than 22 ($HCO_3$–) suggest hypovolemia and hypoperfusion leading to lactate accumulation in the blood. This rule presupposes no other cause of acidosis besides hypovolemia.
[i]Requires an arterial line for instantaneous pressure (variability with respiration) or sampling of arterial blood (base excess or $HCO_3$–).
How to use Table 14.2: Each clinical variable in the top row is easy to assess. The table describes signs of hypo-, euvolemia, and hypervolemia. Exceptions exist for each of the above rules; they are for approximate assessment of volume status. More than one variable typically follows during anesthesia, and they usually confirm each other.

After assessment of a patient's volume status, the essential question: *Is the patient: hypovolemic, euvolemic, or hypervolemic?*

Armed with the answer to this question, the decision is next to either give fluid or not give fluid, depending on the hemodynamic goals of the moment. There are patients who are kept deliberately hypovolemic, or "dry", for example, patients with elevated pulmonary artery pressures, COPD, or after certain surgeries, particularly thoracic surgeries. There are also patients who are best kept hypervolemic or "full", although this is less common. But in general, most caretakers are trying to find euvolemia and maintain it in their patients.

## Calculating Fluid Requirements

One can calculate a patient's fluid requirements using a set of rules. These are summarized in Table 14.3 and an example follows in Table 14.4.

## Fluid Replacement Options

When choosing a fluid replacement option, it is important to differentiate between the various kinds of intravenous fluid used during anesthesia and surgery and in critical care. There are two traditional classes of fluids, crystalloids & colloids (see Tables 14.5 and 14.6):

- **Crystalloids** are the fluids of choice for most minor procedures. They are sterile aqueous solutions which may contain glucose, various electrolytes, organic salts, and nonionic compounds. Some examples of these solutes are sodium chloride, potassium chloride, sodium bicarbonate, calcium carbonate, sodium acetate, sodium lactate, and sodium gluconate. The fluids themselves are known colloquially as normal saline, Ringer's Lactate, Normosol-R®, etc. Table 14.5 lists the ingredients and characteristics of some commonly used IV fluids; Table 14.6 lists typical practical applications of these fluids in routine anesthetic care.
- **Colloids** are aqueous solutions of derivatized human serum protein macromolecules (albumin 5% or Plasmanate); or carbohydrate macromolecules (Hetastarch). They are prepared so as to be nonimmunogenic and noninfectious. Because of their component solute sodium chloride, they have tonicity and osmolality like crystalloid solutions. But additionally, their macromolecule solute components give them oncotic pressure similar to serum. *The result is that these solutions remain in the intravascular space longer (hours to days) than do crystalloids (minutes to hours).*

Colloids are therefore thought to improve the patient's intravascular volume and perfusion and minimize weight gain and edema, as compared with crystalloids.

**Table 14.3 Calculating perioperative fluid requirements sections 1 + 2 + 3 + 4 = Total fluid needed; *give as directed in italics.***

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. **Basal fluid requirement** based on weight of the patient in kg. 10 kg infant 40 ml/h;80 kg adult 120 kg/h. *Give continuously.* | | | | | | | | | | |
| Wt (kg) | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| Hourly maintenance ml/h | 40 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 |
| 2. The **"NPO" deficit**: basal requirement times hours since fasting started: (8 h × 1.) *Replace in the first hour or two.* | | | | | | | | | | |
| NPO deficit after 8 h (ml) | 40 × 8 = 320 | 60 × 8 = 480 | 70 × 8 = 560 | 80 × 8 = 640 | 90 × 8 = 720 | 100 × 8 = 800 | 110 × 8 = 880 | 120 × 8 = 960 | 130 × 8 = 1,040 | 140 × 8 = 1,120 |
| 3. The **replacement for surgical blood loss**[a] is three (3) times the estimated blood loss: *Give as the loss occurs.* | | | | | | | | | | |
| Blood loss (ml) | 25 | 50 | 75 | 100 | 150 | 200 | 300 | 400 | 500 | 750 |
| Replacement for blood loss (ml crystalloid) | 75 | 150 | 225 | 300 | 450 | 600 | 900 | 1,200 | 1,500 | 2,250 |
| 4. The **replacement**[b] **for "third-space losses"** is related to the type of surgery: *Give as needed to support blood pressure, CVP, and urine output.* | | | | | | | | | | |
| Type of surgery | Minor or peripheral surgery such as ankle fracture, ENT surgery. | | | Intermediate such as hip surgery, healthy laparoscopy. | | | Heavy losses such as intraabdominal sepsis, radical neck dissection, large flaps. | | | |
| Replacement for third space loss (ml/kg/h) | 1–3 ml/kg/h | | | 3–6 ml/kg/h | | | 6–10 ml/kg/h or more | | | |

**How to use Table 14.3: There are four (4) separate components to be calculated to replace losses with intravenous fluids: (1) Maintenance fluid requirement (in ml/h); (2) NPO deficit from fasting before surgery (in ml); (3) Blood loss to be replaced (in ml); and (4) The so-called "third-space losses" which occur by expansion of the interstitial space after trauma or illness (in ml/h). This table's four sections show how to calculate each component. Add them up and then administer fluid *as indicated by the italics.***

**[a]Notes: (a) Using crystalloid the rule is: administer roughly three times the EBL. (b) If colloid is used to replace EBL, the ratio is about 1 to 1.**

**[b]Notes: (a) Use crystalloid to replace third space losses. (b) If colloid is used, less is needed.**

**Table 14.4 Example fluid replacement calculation.**

| |
|---|
| **Patient and procedure:** |
| An 80 kg male patient undergoes a 1-h tonsillectomy at 8:00 am after being made NPO at midnight. |
| **Blood Loss:** |
| Estimated blood loss is ultimately 250 ml |
| **Crystalloid vs. colloid choice:** |
| Crystalloid is adequate, no colloid needed for this small volume blood loss. Lactated Ringers is optimal though saline could be used. |
| **Replacement:** |
| (Calculated from the four parts of Table 14.3.) |
| Total crystalloid administered is: |
| 120 ml (maintenance for the 1 h duration) |
| +960 ml (for the NPO deficit) |
| +750 ml (for the blood loss) |
| ±250 ml (for the third space loss, estimated at 2 ml/kg/h) |
| =2080 of NS or LR over the 2 h perioperative period. |
| **Postoperative maintenance:** |
| May be 120 ml per hour with adjustments made based on vital signs and urine output. |

Colloids may even under some circumstances draw interstitial fluid back into the intravascular space.

*Albumin* 5% is the colloid most commonly used as a volume replacement. If diluted from 25% albumin it must be diluted with NS, not with hypotonic solutions like water or ½ NS. Improperly diluted albumin can cause fatal hemolysis after infusion into a patient.

*Plasmanate® (purified protein fraction 5%)*, contains mostly albumin (88%) but also alpha- and beta- (12%) and some gamma-globulins (1%). Plasmanate is heat-treated to be nonreactive immunologically. But, Plasmanate®, like albumin, is considered to be a "blood product" and therefore unacceptable to many individuals on religious or other grounds. It has 145 meq/l NaCl and is isotonic to plasma.

*Hetastarch®* (ethoxylated amylopectin 6%), is a solution of derivatized macromolecular complex carbohydrates. It has the same tonic, osmotic, and oncotic properties as the protein solutions, but is derived from vegetable matter, and therefore is not a "blood product" and is acceptable to many otherwise opposed to receiving derivatized plasma, such as Jehovah's Witnesses. Hetastarch® and other similar products are also much less expensive than protein derivative solutions.

**Table 14.5 Ingredients and characteristics of commonly used crystalloid and colloid fluids.**

| IV fluid | $H_2O$ | D5W | NS | D5½ NS + KCl 20 meq/l | LR | D5LR | Normosol-R® | Plasmalyte-148® | Hetastarch | Albumin 5% | Plasmanate 5% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 7.0 | 4.0 | 5.5 | 4.5 | 6.5 | 4.9 | 7.4 | 5.5 | 5.5 | 7.4 | 7.4 |
| Mosm/l | 0 | 252 | 308 | 446 | 279 | 525 | 296 | 294 | 310 | 309 | 280–285 |
| Na meq/l | 0 | 0 | 154 | 77 | 130 | 130 | 140 | 140 | 154 | <160 | 145 |
| K meq/l | 0 | 0 | 0 | 0 | 4 | 4 | 5 | 5 | 0 | <2 | 0.25 |
| Cl meq/l | 0 | 0 | 154 | 77 | 109 | 109 | 98 | 98 | 154 | 130 | 100 |
| Ca meq/l | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 0 |
| Mg meq/l | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 0 |
| $HCO_3$ meq/l | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lactate mmol/l | 0 | 0 | 0 | 0 | 28 | 28 | 0 | 0 | 0 | 0 | 0 |
| Acetate mmol/l | 0 | 0 | 0 | 0 | 0 | 0 | 27 | 27 | 0 | 0 | 0 |
| Gluconate Mmol/l | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 23 | 0 | 0 | 0 |
| Glucose mg/dl | 0 | 5000 | 0 | 5,000 | 0 | 5,000 | 0 | 0 | 0 | 0 | 0 |
| Colloid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 g/L starch | 40–50 g/L human albumin | 50 g protein: (88% albumin; 12% $\alpha$,$\beta$; 1% $\gamma$) |
| Kcal/l | 0 | 170 | 0 | 170 | 9 | 179 | 15 | 21 | 0 | 0 | 0 |

Serum osmolality sosm is 275–295 and may be calculated by 2(Na+K)+glu/18+BUN/2.8

**Table 14.6 Advantages, disadvantages, and special properties of commonly used intravenous fluids.**

| Fluid → | $H_2O$ | D5W | D5 ½NS + 20 meq KCl/l | NS | Lactated Ringer's | Normosol-R® or Plasmalyte-148® | Hetastarch® | Albumin 5 % or Plasmanate® 5% | Plasmalyte-148® |
|---|---|---|---|---|---|---|---|---|---|
| Typical use | Diluent for small volumes of medication – hypotonic – may not be infused intravascularly because it will lyse RBCs | Keep open fluid used just to give medicines | Classic maintenance fluid for medicine patients on the ward having nothing but insensible and obligatory losses. | Classic replacement fluid for initial resuscitation for dehydration and blood loss | Classic replacement fluid for perioperative surgical losses | Used in cardiac, renal, hepatic, especially transplantation surgeries because it produces no lactate load | Volume expansion in cases where losses have exceeded 2 L | Volume expansion in cases where losses have exceeded 2l. Volume expansion in cases where interstitial edema and hypoalbuminemia exist. | Used in cardiac, renal, hepatic, especially transplantation surgeries |
| Advantages | NaCl free, so good to dilute antibiotics and other salts. | NaCl free, will keep withdrawing alcoholic patients from becoming hypoglycemic if fasted. | Correct amount of NaCl & free water for insensible losses | Cheap, may be used to administer blood | This is used to prevent the metabolic acidosis found after NS used to replace blood losses | Calcium free so it may be used to administer blood just as saline is. | Inexpensive, contains fixed amount of sodium; not derived from blood | May be given in large quantities without concern for coagulopathy other than dilutional. | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Disadvantages | Hypotonic, dangerous to infuse; causes $H_2O$ intoxication if given enterally in excess | May lower Na, contains too much glucose for many patients if infused rapidly | Not ideal to bolus in hypovolemic or oliguric patients: NS or LR better | May cause mild **metabolic acidosis** if used to replace moderate blood loss; contains too much sodium for some patients | **Calcium** in it makes it **incompatible** with citrated **blood products**. Patients with liver disease may not tolerate lactate due to impaired gluconeogenesis. | Not a source of calories as a maintenance fluid; more expensive than NS | Given in quantities greater than 2L it may induce coagulopathy | Derived from blood, which is unacceptable to some patients. Expensive. (Plasmanate 5%: non-albumin proteins may be immunogenic: avoid Plasmanate in transplant patients.) |
| Special properties | Hurts veins and causes hemolysis. Don't use to dilute 25% albumin | Does not hurt veins; gives 20 kcal per 100 ml, prevents hypoglycemia | This is sold with the added KCl because 3 liters will replace exactly the obligate daily K+ loss in adults | May be given intraoperatively to mildly hyponatremic patients to help normalize serum sodium levels very gently. | Avoid in anephric patients because of the small amount of $K^+$ in it. | Does not have glucose so alcoholic patients may need to have glucose monitored intraoperatively to avoid hypoglycemia. | Inhibits von Willebrand factor (vWF) function on platelets. | Albumin: Has a variable amount of sodium chloride in it. |

## Introduction to Acid-Base Analysis

Acid-base equilibrium is important because almost all cellular biochemical reactions take place in the aqueous phase. The concentration of hydrogen ions (the pH) in the various fluid compartments controls, among other things, the conformation of proteins and the feasibility and speed of all the reactions. The pH is highly regulated; cellular death will occur quickly if the normal ranges are exceeded by being too basic (high pH) or too acidic (low pH). So diagnosis and treatment of acid-base disturbances must be accurate, often immediate.

The arterial blood gas panel consists of four values: pH, $PaCO_2$, $PaO_2$, and $HCO_3^-$ (or a related derivative calculation of $HCO_3^-$ called the Base Excess, BE). It is important to know the inspired oxygen concentration ($FiO_2$) paired with each individual blood gas to determine the quality of oxygen delivery to the blood.

It is also important to know the Anion gap (AG) drawn from arterial or venous blood. Anion gap is a derived quantity that is obtained by subtracting the values for serum chloride and $HCO_3^-$ from serum sodium. The normal AG is 12–20 meq/L. To check this, here we substitute the following normal serum electrolyte values into the equation: ($Na^+ – HCO_3^- – Cl^- = AG$); [Normals: 140 – 24 – 101 = 15 meq/L, with a range of 12–20 meq/L].

The first step in blood gas analysis is to decide whether the patient has a normal pH (7.35–7.45), is acidemic (low pH, less than 7.35), or is alkalemic (high pH, greater than 7.45).

1. If the blood gas shows the patient is acidemic (pH < 7.35), then:
   (a) Look at the $PaCO_2$. If it is greater than 40 mm Hg, then the patient has respiratory acidosis. Respiratory acidosis is caused by excess dissolved $CO_2$ in the blood, due to either inadequate ventilation of $CO_2$ out of the lungs or excess production of $CO_2$ in the body. There are several possible underlying causes: hypoventilation, which is decreased minute ventilation (decreased respiratory rate or decreased tidal volume); obstruction of the small airways (COPD, asthma); overdosage of alcohol, sedatives, opioid medications; or neuromuscular disease (like myasthenia gravis). Or, overproduction of $CO_2$ may be from hyperthermia or overfeeding.
   (b) If the $PaCO_2$ is normal or slightly decreased, then the patient has a metabolic acidosis. This is caused by one of several dissolved "acids" or acidic substances in the blood (either endogenous, such as lactic acid, or exogenous, such as ethanol) that are lowering the pH. In response, the body may encourage hyperventilation to counterbalance this to some extent.

There are two kinds of metabolic acidosis: Anion gap-acidosis (AG > 20 meq/L) and Non-anion gap or Normal anion gap acidosis (AG < 20).

Anion gap acidosis is summarized by the classic mnemonic MUDPILES which is used to recall its most likely causes: Methanol, Uremia, Diabetic ketoacidosis, Propylene glycol, Isoniazid (INH), Lactate, Ethylene glycol, and Salicylates. The mnemonic is useful but almost quaint in that it recalls a number of toxins or drug side effects rarely seen today clinically.

Non-anion gap acidosis (also known as hyperchloremic acidosis) is caused by either diarrhea, administration of NaCl solutions (normal saline) especially during surgery or after traumatic blood loss, acetazolamide use, or renal tubular acidosis. All four have the common etiology of bicarbonate loss. Therefore, the treatment of metabolic acidosis is the administration of intravenous bicarbonate solutions or a precursor: lactate, citrate, or acetate.

2. If the pH is greater than 7.45 (recall that normal pH is 7.35–7.45) then the patient has alkalemia:
   (a) Look at the $PaCO_2$ as before. If it is less than 40 mm Hg, then the patient has respiratory alkalosis. Respiratory alkalosis is caused by decreased levels of dissolved $CO_2$ in the blood, due to either hyperventilation of $CO_2$ out of the lungs or decreased production of $CO_2$ in the body. There are several possible underlying causes: central or CNS-induced hyperventilation, which is increased minute ventilation (increased respiratory rate and/or increased tidal volume), usually from anxiety or a CNS lesion; the respiratory stimulus of altitude; pregnancy; or too much mechanical ventilation. Alternately, underproduction of $CO_2$ may be from hypothermia or muscle relaxation from nondepolarizing muscle relaxant drugs. One can correct respiratory alkalosis by adjusting ventilation or treating anxiety with sedatives.
   (b) If the $PaCO_2$ is normal or slightly increased, then the patient has a metabolic alkalosis. This is caused by one of several causes: vomiting or loss of protons in gastric secretions owing to nasogastric or orogastric suction (classically, in the face of gastric outlet obstruction); diuretic use (classically after heavy furosemide diuresis in the postoperative period – especially after cardiac surgery); antacid use; or hyperaldosteronism. Metabolic alkalosis needs to be corrected because the condition predisposes to dysrhythmias, cerebral vasoconstriction, and coronary vasoconstriction. Also, in mechanically ventilated patients, the condition leads to a vexing

secondary effect: the retention of $CO_2$ in the blood, which makes weaning from mechanical ventilation more troublesome in some patients. One corrects metabolic alkalosis by simply infusing normal saline, potassium chloride, or both, intravenously, or, in severe cases, dilute hydrochloric acid is carefully infused centrally. Acetazolamide may also be used if the patient can't tolerate the increased volume load of intravenous solutions.

In summary, rules for the analysis of blood gases and acid-base status are found in the two tables below. Table 14.7 summarizes the four primary acid-base disorders. Table 14.8 quantifies the degree of pH, $PaCO_2$, $PaO_2$, and $HCO_3^-$ secondary compensation expected for the purest examples of the various acid-base disturbances. In actual clinical practice, a patient may manifest one, two, or three combined acid-base disturbance, all of which ultimately contribute to the pH. Therefore the clinicians overall goal is to restore the pH to the normal range, or near to it, as quickly as possible.

**Table 14.7 Summary of acid–base disorders.**

| Disorder | pH | $PaCO_2$ | $HCO_3$ |
|---|---|---|---|
| Respiratory alkalosis | ↑ | ↓ | ↓ |
| Respiratory acidosis | ↓ | ↑ | ↑ |
| Metabolic alkalosis | ↑ | ↑ | ↑ |
| Metabolic acidosis | ↓ | ↓ | ↓ |

**Table 14.8 Expected compensatory responses in primary acid–base disorders.**

| | |
|---|---|
| Acute respiratory acidosis | No change in base deficit or excess |
| Acute respiratory alkalosis | No change in base deficit or excess |
| Chronic respiratory acidosis | Base deficit or excess = $0.4 \times (PaCO_2 - 40)$ |
| Chronic respiratory alkalsosis | Base deficit or excess = $0.4 \times (PaCO_2 - 40)$ |
| Acute metabolic acidosis | $PaCO_2 = 40$ + base deficit or excess |
| Acute metabolic alkalosis | $PaCO_2 = 40 + (0.6 \times$ base deficit or excess) |

**Adapted from Acute Heart Failure By Alexandre Mebazaa, Mihai Gheorghiade, Faiez M. Zannad; Published by Springer, 2008 ISBN 1846287812, 9781846287817 page 464.**

## Transfusion of Blood Products: Goals and Indications

The goals of transfusion are several; one or more may apply to any given patient. Transfusion may be done prior to surgery to replace RBC volume in acutely or chronically anemic patients. It is used during and after surgery to replace traumatic, intraoperative, or postoperative losses of red blood cells. In cases of coagulopathy, it is done to replace coagulation factors and thereby, restore hemostasis. In autoimmune or dilutional thrombocytopenia, transfusion of platelets may at least partly correct these conditions and allow thrombosis to occur normally. In cases of platelet inactivity due to disease or medications (e.g., NSAIDs), a small amount of platelets (one unit rather than 6 pooled units) can serve as a catalyst and initiate platelet thrombus formation and achieve the first steps of hemostasis. Finally, long after surgery, or in protracted illnesses or recuperation, it is often necessary to give RBC when a critical anemic threshold is met.

As the length of procedure and blood loss increase, replacement of blood products may be needed. Besides the clinical volume criteria listed above in Table 14.3, the hematocrit (HCT) is another clinical datum used for assessing red blood cell volume (RBCV) and anemia indirectly. HCT is really a surrogate measurement for RBCV, which is impossible to measure practically.

As a case begins, one can calculate a patient's allowable blood loss (ABL) by using the formula below in Fig. 14.2. This gives the anesthesiologist a guide to know how much blood loss can occur prior to starting a blood transfusion (Fig. 14.3).

Serial HCT readings (plus the clinical criteria used to assess volume status, see Table 14.3) are the basis for choosing to transfuse blood cells. By practical convention, one gram of Hb is equivalent to 3 HCT percentage points. *For example, if a patient has a Hb of 10 g/dl, the HCT will be approximately 30.* Furthermore, each unit of PRBC in an adult is expected to raise the HCT by

**Allowable Blood Loss (ABL) Formula**

$$EBV \times (HCT_{initial} - HCT_{final}) / HCT_{inital}$$

*where* $HCT_{final}$ *= lowest acceptable hematocrit*

**Figure 14.2 Allowable Blood Loss (ABL) Formula.**

**Estimated Blood Volume (EBV) Formula**

EBV = weight (kg) x average blood volume

*Note: Avg. blood volume in adult male = 75 ml/kg*
*Avg. blood volume in adult female = 65 ml/kg*

**Figure 14.3 Estimated Blood Volume (EBV) Formula.**

3 points. If such a predicted increase does not occur, one should be concerned about ongoing blood loss, hemolysis, or hemodilution with excess IV fluids.

HCT is drawn from venipuncture, peripheral or central venous line, or arterial line. One must interpret HCT carefully, because dilution from crystalloid or colloid may cause significant variation in HCT even without any significant blood loss.

Decisions about giving platelets and plasma or plasma derivatives are based, in a similar way, on both clinical criteria and lab values. Diagnostic lab studies such as coagulation panels (PT, PTT, INR, platelet counts), and more specific studies such as specific factor levels, may be used in more challenging cases such as hepatic transplantation (high volume fluid turnover), or in the setting of end-stage liver disease (because of the confounding factor of pre-existing coagulopathy). Patients with known hemophilia or platelet abnormalities may also warrant more specialized studies of coagulation in the perioperative period.

## Using CVP and PA Catheters for Volume Assessment

If surgical blood loss is expected to exceed one liter, placement of a CVP should be a consideration. The insertion of these lines is discussed in Chap. 15. Insertion of a CVP line allows convenient monitoring of right atrial (RA) pressure, central venous oxygen saturation ($CvO_2$), and serial HCT-all of which are useful to assess volume status and RBCV (see Table 14.2).

The use of pulmonary artery (PA) catheters is much less common than the use of CVP catheters. They nevertheless are useful at assessing volume status more precisely than a CVP can. PA catheters also allow sampling of mixed venous ($SvO_2$) blood, which is a more accurate means of assessing total-body oxygen delivery than is $CvO_2$. PA catheters also allow one to manage fluids

meticulously in the setting of CHF, COPD, and pulmonary hypertension. One typically measures the PA occlusion pressure (PAOP or wedge pressure) intermittently, in order to reduce the hazard of PA perforation. Equally valid but safer is to serially follow the PA diastolic pressure trends. Armed with this information about volume status, one can replace fluid accordingly, but usually with smaller doses of fluid (100 or 200 ml at a time). The advantage of this is that less excess fluid will be administered over time to a vulnerable patient.

## Transfusion of Blood Products: Practical Aspects

There are some general considerations to keep in mind when transfusing blood products. Transfusion is much more hazardous, expensive, and controversial than infusing crystalloid or non-blood-product derived colloids. Fortunately, most anesthetics are accomplished with crystalloid administration only, or crystalloid plus colloid. When transfusion is indicated because of coagulopathy, anemia, or massive blood loss, it should be given promptly to prevent end-organ damage and death from life-threatening anemia, tissue hypoxia, and acidosis.

Blood products available for transfusion include:

- **Red blood cells** (RBCs) given for anemia or ongoing blood loss
- **Fresh-frozen plasma** (FFP) given for mild coagulopathy (PT or INR elevation or severe fibrinogen deficiency)
- **Platelets** given for immune or dilutional thrombocytopenia
- **Cryoprecipitate** given for severe coagulopathy and Factor VIII deficiency
- **Whole blood** is rarely used, since blood is typically separated into components (RBC, plasma, and platelets) in order to allow more efficient use
- Other more specific coagulation factors (human or recombinant) may be used to treat coagulopathy

More specialized factors used to treat coagulopathy include activated Factor VII (FVIIa), a newer agent given for severe diffuse postsurgical coagulopathy when there is no discrete source of bleeding. FVIIa has also been used to treat intracranial hemorrhage. Another specialized factor product is known as Factor IX concentrate. This is a combination of Factor IX (i.e., Christmas factor, antihemophilic factor B), Factor II (prothrombin), Factor X (Stuart-Prover Factor), and low non-therapeutic levels of Factor VII (proconvertin), all derived from human pooled plasma. The indication for giving them is for severe coagulopathy. These products are also used before surgery if a specific Factor IX deficiency (i.e. hemophilia) is demonstrated with lab studies.

## Hazards of Transfusion

Some of the hazards of transfusion are very well known and quantified, and others not so well known. These hazards are discussed also in Chap. 16, Common Intraoperative Problems. Here we will emphasize the major risks of transfusion and how they relate to the decision to transfuse. These include infection, immunosuppression, long-term morbidity, and transfusion reactions.

The public is most concerned about the **risks of transfusion-associated infection**, especially viral infection, from HBV, HCV, CMV, and HIV. There are other infectious hazards as well, listed in Table 14.9.

There are some emerging data on **long-term immunosuppression and other increased morbidity and mortality following transfusion**. This is not well described in the literature. The difficulty in all transfusion-related outcomes research is separating true causes of bad outcomes from mere epiphenomena or anecdotal evidence.

### Transfusion Reactions (Also see Chap. 16, Common Intraoperative Problems)

Transfusion reactions come in varying kinds and degrees of severity. Table 14.10 lists the various kinds of immunologically-mediated transfusion reactions.

The **most common** type of **serious transfusion reaction** is the **major acute hemolytic reaction** (from ABO or Rh- incompatibility): The usual cause is clerical error prior to transfusion. The problem is that the transfusion recipient has antibodies against donor RBC membrane ABO or Rh- antigens. The antibodies bind to the donor RBC membrane antigens and activate complement, inducing hemolysis. The free Hb goes into the bloodstream and can damage the kidneys. There are many other sequelae to the hemolysis. The treatment for such a reaction is first to immediately stop transfusion, resend patient and unit blood for re-crossmatch (clerical or crossmatching errors are most likely), use mannitol and furosemide for diuresis, monitor urine volume and hemoglobin, check serum haptoglobin to monitor hemolysis, and support hypotension with volume, pressors, inotropes. Major acute hemolytic reactions are often fatal.

Compatibility and anticipating reactions is therefore the greatest concern when transfusing blood. Table 14.12 shows recipient versus donor compatibility, for various blood products. It allows one to identify the recipient, choose

**Table 14.9 Infectious risks of transfusion and estimates of occurrence.**

| Disease | Microorganism | Transmitted in this blood product | Incidence per unit transfused | Transmissible by "needle stick" or blood exposure | Prophylaxis or treatment | Comments |
|---|---|---|---|---|---|---|
| AIDS or HIV disease | HIV 1 virus | All blood products, not in albumin | 1:500,000 | Yes | HAART | Consider post exposure prophylaxis, consult ID specialist |
| Hepatitis C | HCV virus | All blood products, not in albumin | 1:100,000 | Yes | Interferon alpha 2a plus ribavarin | Liver transplantation not contraindicated in some pts who have liver failure from HCV |
| Hepatitis B | HBV virus | All blood products, not in albumin | 1:70,000 | Yes | HBIg plus Lamivudine | More common in Asia and complicates posttransplant liver function |
| CMV infection | Cytomegalovirus | RBC, platelets | 1:50 | Yes | WBC filters; Frozen deglycerolized RBC, screen donors | CMV-free blood now only indicated for immunosuppressed pts |
| Malaria | *Plasmodium falciparum* | RBC | 1:3,000,000 | Yes | Antimalarial therapy | Not common in nonendemic regions |
| Bacterial infection | *Staphylococcus* spp; *Salmonella* spp; *Enterobacter* spp; *Serratia marcescens* | Platelets | 1:15,000 | Yes | Broad then narrow antibiotic coverage according to cultures | Platelets pooled and administered at room temperature |
| Bacterial infection | *Staphylococcus* spp; *Salmonella* spp; *Enterobacter* spp; *Serratia marcescens* | RBC | 1:1,000,000 | Yes | Broad then narrow antibiotic coverage according to culture results | Bacterial sepsis from blood products has a high mortality of 25 % according to some authors, so it should be treated aggressively |

**Table 14.10 Types of transfusion reactions.**

| Type | Incidence | Commonest after administration of | Symptoms | Treatment or prophylaxis | Immune Mechanism | Time course | Fatality |
|---|---|---|---|---|---|---|---|
| Non-hemolytic febrile reaction | Common (several percent for platelets) | Platelets, RBC | Chills, fever | Acetaminophen, ibuprofen, diphenhydramine, leukocyte reduction of transfused blood. | Mediated by inflammatory cytokines in the recipient | Onset 1 6 h after transfusion | Not fatal |
| Acute hemolytic transfusion reaction | 1:10,000 occurring with resulting 20 fatalities per year in USA | Clerically mismatched blood. Worst is from Type A donor given to Type O recipient | Flank pain if awake, bloody or dark urine, shock. This is the classic severe transfusion reaction | Careful crossmatching and checking of blood by caretakers before administration. To treat, see text | Hemolysis of the donor red blood cells by host IgM antibodies usually related to ABO blood group incompatibility. Complement is activated | May begin minutes after transfusion begun. | May be fatal, may cause renal failure |
| Delayed hemolytic transfusion reaction | Rare except in patient receiving many transfusions such as SCD[a] patients | Multiple RBC transfusions as for SCD[a] | Fever, lower than expected blood hemoglobin , jaundice, urobilinogenuria | Supportive therapy. | Delayed hemolysis of blood from alloimmunization developing in recipient. IgM antibodies and complement are involved | Onset one to several weeks | May range from subclinical to fatal |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Anaphylactic reaction | 1:20,000 | Most common in recipients with selective IgA deficiency | Shock, breathing difficulties, wheezing, etc | Supportive treatment as for anaphylaxis | IgE and IgA mediate, histamine and other factors released in anaphylaxis, and complement may be involved | Within minutes of transfusion. | May be fatal |
| Transfusion-related acute lung injury (TRALI) | 1:2,000 | Large amounts of whole blood or plasma | May be mild to life threatening: Respiratory distress, fever, non-cardiogenic pulmonary edema, hypotension | Supportive, including mechanical ventilation. | Antibodies in donor blood product against HLA (A, B, C, DR) and other antigens in the recipient. Pulmonary capillary alveolar leak | Onset hours, patients recover fully within 96 h | Mortality is less than 10% |

[a] ***SCD*** **Sickle cell disease.**

**Table 14.11 Transfusion of bloodproducts: description, indications, contraindications.**

| Product | Packed red blood cells (PRBC) | Fresh frozen plasma | Platelets | Cryoprecipitated Antihemophilic Factor |
|---|---|---|---|---|
| Synonyms | Packed Cells, Red Cells, Packed Red Blood Cells, RBCs, PRBCs | FFP. FFP24 | Random donor platelets, RDPs. Platelets pheresis are single donor platelets, or SDPs | Cryoprecipitate, cryo, pooled cryo |
| Description | RBC are prepared from whole blood with plasma & platelets removed. HCT of RBC is 70%. Citrate anticoagulant added | Noncellular portion of blood that is separated & frozen after donation. It may be prepared from whole blood or collected by apheresis. Citrate anticoagulant added | 4-10 RDPs are pooled by blood bank. SDPs are ready for transfusion. Citrate anticoagulant added | A cryoprecipitate unit is prepared by thawing one unit of FFP between 1-6 °C & recovering the cold insoluble precipitate. Cryoprecipitate contains fibrinogen, Factor VIII:C, Factor VIII: vWF, Factor XIII, and fibronectin. Citrate anticoagulant added |
| Indications | *Not bleeding & stable:* (a) Patients without cardiovascular dz & esp. younger pts, keep Hb range 7 – 9 g/dl (b) Patients with cardiovascular disease: Keep Hb in the range ≥ 10 g/dl | 1. Active bleeding due to deficiency of multiple coagulation factors, or risk of bleeding due to deficiency of multiple coagulation factors. 2. Severe bleeding due to warfarin therapy, or urgent reversal of warfarin effect. | 1. Use platelets prophylactically to prevent bleeding at pre-specified low platelet counts. 2. In general, maintain platelet count >10,000/$mm^3$ in stable, non-bleeding patients, >20,000/$mm^3$ in unstable non-bleeding patients and >50,000/$mm^3$ in patients undergoing invasive procedures or actively bleeding | 1. Bleeding associated with fibrinogen deficiency (< 100 mg/dl) 2. Bleeding associated with Factor XIII deficiency. 3. Prophylactic treatment for head trauma associated with DIC |

| | | | | |
|---|---|---|---|---|
| | *Bleeding:*<br>(a) 1500-2000 ml (30 %) blood loss: transfusion of RBC likely<br>(b) › 2000 ml blood loss: RBC transfusion needed<br>***In all cases: Use clinical judgment & check HCT before transfusing.*** | 3. Massive transfusion with coagulopathic bleeding<br>4. Bleeding or prophylaxis of bleeding for a known single coagulation factor deficiency for which no concentrate is available<br>5. Thrombotic thrombocytopenic purpura<br>6. Rare specific plasma protein deficiencies, such as C1-esterase inhibitor | 3. Intraoperative cardiovascular, thoracic, or neurosurgical patients, maintain platelets above 100,000/$mm^3$ | |
| **GENERAL INFORMATION** | | | | |
| Contraindications | 1. Do not give if patients are not bleeding, healthy, BP and HR normal, and HCT is greater than 21<br>2. Do not transfuse in other patients if hemoglobin is greater than 10 | 1. Not to be used for increasing blood volume or albumin concentration<br>2. Do not use for treating coagulopathy that can be corrected with Vitamin K<br>3. Do not use to normalizing abnormal coagulation screen results, in the absence of bleeding | Do not use in patients with autoimmune thrombocytopenia or thrombotic thrombocytopenic purpura except for life-threatening hemorrhage | Do not transfuse cryoprecipitate unless laboratory studies confirm deficiency of a specific clotting protein for which this component is indicated (e.g., fibrinogen) |

**Table 14.12 Blood type compatibility matrix.**

| Recipient blood type | Compatible donor blood type | | | |
|---|---|---|---|---|
| | PRBC | Whole blood | Plasma | Platelets |
| O+ | O+, O– | O+, O– | O, A, B or AB | O+, O– |
| O– | O– | O– | O, A, B or AB | O– |
| A+ | A+, A–, O+ or O– | A+ or A– | A or AB | A+, A–, O+ or O– |
| A– | A– or O– | A– | A or AB | A– or O– |
| B+ | B+, B–, O+ or O– | B+ or B– | B or AB | B+, B–, O+ or O– |
| B– | B– or O– | B– | B or AB | B– or O– |
| AB+ | AB+, AB–, A+, A–, B+, B–, O+, or O– | AB+ or AB– | AB | AB+, AB–, A+, A–, B+, B–, O+, or O– |
| AB– | AB–, A–, B–, or O– | AB– | AB | AB–, A–, B–, or O– |

**How to Use Table 14.12: Find the blood type of the recipient (your pt) in the left hand column. Then choose which blood product you would like to transfuse (if indicated) across the top The intersecting box will say which donor types are compatible. Cable R, *Carlson B, Chambers L, Kolins J, Murphy S, Tilzer L, Vassallo R, Weiss J, Wissel ME. Practice guidelines for blood transfusion: a compilation from recent peer-reviewed literature. 2ed. Washington, DC: American National Red Cross, 2007.***

the blood product to be given, and then determine which donors would be compatible with the recipient.

Even if donor and recipient are compatible by crossmatching, there may still be immune reactions to blood transfusion. The most common benign transfusion reaction is the minor febrile non-hemolytic transfusion reaction (mild immunoglobulin incompatibility or cytokine reaction). This is more common than an acute hemolytic transfusion reaction and is much less problematic. Treatment involves administration of diphenhydramine 25 mg IV, acetaminophen 500 mg, or ibuprofen 400 mg enterally, and monitoring vital signs along with urine output. Often, the transfusion may continue if the patient is stable.

Another problem in crossmatch-compatible blood transfusion is known by the acronym TRALI (transfusion-related acute lung injury). It has an estimated incidence of 1:2000 and is thought to be mediated by leucoagglutinating

antibodies in the donor plasma directed against HLA antigens in the recipient. It manifests as non-cardiogenic pulmonary edema, and has a mortality rate of less than 10 percent.

### Other Problems Associated with Transfusion

**Hypothermia** is common problem associated with transfusion. As with any infusion, use an inline IV fluid warmer and don't warm blood products or fluids in a microwave or non-FDA-approved device.

**Hyperkalemia** may occur because PRBCs, especially those close to expiration, have a significant $K^+$ load. Be sure to monitor potassium in patients with renal insufficiency who receive PRBCs.

**Hypocalcemia** is also common because the citrate anticoagulant used to store blood products is a calcium binder. If given in enough quantity (8–10 units of blood), citrate may cause transient hypocalcemia manifested as vasodilatation and hypotension. In order to treat, one should obtain an ionized (not standard) calcium level, and administer 1–2 g of calcium chloride or calcium gluconate through a central catheter or large iv. Do not give calcium with bicarbonate or it will precipitate and cause catastrophic tissue necrosis.

## Transfusion: Legal and Ethical Issues

There are legal, professional, religious, and economic issues related to transfusion. Physicians have a legal duty to give blood when indicated (and permitted by the patient) to prevent organ damage from hypotension, tissue hypoxia, and acidosis. A competent patient, however, also has the absolute right to refuse transfusion or any therapy. Informed consent applies to blood transfusion and some institutions have a dedicated form for obtaining it.

**Religious or philosophical issues:** Jehovah's Witnesses and others are doctrinally opposed to transfusion of blood products and should be queried regarding their wishes during anesthesia and postoperative care. Remember that besides PRBCs many other products (albumin, Plasmanate®, platelets, cryoprecipitate, as well as factor IX concentrates) are derived from human blood. However, patients' specific beliefs about these products vary, and a detailed conversation and written documentation of a patient's wishes will avoid confusion.

**Professional issues:** It is wise to include other physicians and caretakers in discussions about transfusion prior to initiation. It is also a good practice to use evidence based professional guidelines for transfusion therapy (see Tables 14.11 and 14.12). Patients and families are very worried about

transfusion and will want to know the indications (Table 14.10 clarifies these) and give informed consent. Transfusion and the use of coagulation factors is fraught with complications and therefore it is wise to achieve consensus among the caretakers, patient, and family before transfusing. The standard guideline thresholds and dosages for transfusion of various blood products are listed in Table 14.11.

**Economic issues:** Transfusion is very expensive (compared with infusing crystalloid or colloid) as are the recombinant-derived blood proteins. Usually it's wise to confer with others about cost-effectiveness before prescribing.

## Case Study

*A 25-year-old otherwise healthy woman is to undergo radical resection of a pelvic sarcoma with prosthetic reconstruction to attempt to salvage the hip joint and thigh. The surgeon estimates blood loss will be 2–5 liters, depending on the findings at operation and extent of major vascular involvement. The estimated surgical time is 6 h. She has a peripheral 14 G IV, a three-lumen central venous catheter in the right internal jugular vein, and a 20G right radial arterial line. She has 4 units of packed red cells available. She weighs 60 kg. Her preoperative hemoglobin and hematocrit are 12 and 36 respectively. She has fasted overnight and is scheduled for the first case in the morning.*

*How will you estimate her basic fluid requirements for the case?*

You can estimate her hourly maintenance fluid needs with the "4-2-1" rule, calculating 4 ml/kg/h for the first 10 kg of body weight, 2 ml/kg/h for the next 10 kg, and 1 ml/kg/h for each additional 10 kg. This results in 40+20+4(10)=100 ml/h. Assuming an 8 h overnight fast, her deficit preop is 800 ml. Her ongoing maintenance fluid requirement for 6 h of surgery will be 600 ml. Her estimated blood loss is likely extreme, and will be replaced initially at three times EBL, or some 6–15 L. Clearly, some of this will be replaced with blood or colloid solutions, not merely crystalloid. Her "third space" or interstitial fluid losses will be moderate to severe, depending on whether the peritoneum is exposed by the dissection or not. We can estimate these losses at 6 ml/kg/h or more, totaling 360 ml/h or approximately 2.5 L for the case.

*How low will you let her hemoglobin drop?*
The overwhelming preponderance of the evidence suggests that the optimal Hb target for most patients is 7–9 g/dl. This is true even in the case of stable coronary artery disease, and it is certainly the case for this otherwise healthy young woman. In fact, in volunteers, isovolemic hemodilution to at least 5 g/dl is well tolerated.

*What is her acceptable blood loss?*
ABL is often calculated with a formula based on the assumption that blood loss occurs at a constant rate throughout the case, and that the patient's blood volume remains constant by replacement with blood-free solutions. In this young woman, her estimated blood volume is 65 ml/kg × 60 kg = 4 L. Her ABL, given a starting hematocrit of 36 and an acceptable nadir of 21 (equivalent to a hemoglobin of 7 g/dl), is ABL = 4 L*(36–21)/36 = 1.7 L. In practice, anesthesiologists will check hemoglobin/hematocrit periodically as well as make judgments regarding the rate of ongoing blood loss and the adequacy of volume repletion and thus begin transfusion either earlier or later than when this amount has been lost.

*How will you assess and correct other blood product requirements?*
In sudden blood loss situations such as massive trauma, some authorities recommend empirical administration of packed red cells, plasma, and platelets. In the case of operative losses, it is generally prudent to replace factors by monitoring PT and PTT and platelets by monitoring the platelet count. Keeping the PT less than 1.5 times control and the platelet count above 50,000 is generally recommended, although in the setting of ongoing blood loss, more aggressive replacement is often performed. Fibrin is the ultimate substrate for blood clot, so fibrinogen should also be monitored and kept over 100 mg/dl.

*What options do you have for reducing transfusion requirements?*
There are at least three possibilities. First, controlled hypotension is a strategy to reduce blood loss by reducing the hydrostatic pressure causing blood to leave traumatized blood vessels. Reducing the blood pressure to a mean of approximately 50–60 mm Hg is considered safe in healthy patients and reduces blood loss in a variety of types of surgery. This can be

achieved with short acting beta blockers (e.g., esmolol), high concentration of inhaled agents, or direct acting vasodilators (e.g., nitroprusside). Second, normovolemic hemodilution is a technique, which "pre-dilutes" the blood of the patient to a lower hematocrit prior to surgery, so that surgical blood loss contains fewer red cells. Blood is removed from the patient and stored in the same containers used in the blood bank; it is replaced with crystalloid or colloid solutions in a normovolemic fashion (typically 3:1 or 1:1, respectively, or as guided by a CVP catheter). Later in the case, the patient's own blood is returned by transfusion. Finally, intraoperative cell salvage has been successfully employed in a variety of clinical situations. Blood is aspirated from the surgical field into a reservoir where it is periodically washed and filtered to yield a high hematrocrit blood product from the patient's own blood. It is controversial in cases of malignancy, because theoretically tumor cells can be aspirated and reinfused intravenously. Recently, however, leukocyte depletion filters (which do not allow cells much larger than RBC's to remain in the product to be infused) have been shown to efficiently remove all tumor cells from the aspirated blood. Moreover, it is not at all clear that infusion of tumor cells is actually a risk for metastasis, which requires numerous other cellular steps.

## Suggested Further Reading

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