Introduction

Strategies to reduce requirements for transfusion during surgery continue to be a high priority in clinical care. The long-term sequelae of blood transfusion such as latent viral or transfusion-transmitted infectious disease continue to be a source of concern to patients and physicians. Acute normovolemic hemodilution is one of the strategies used to reduce the need for blood transfusion.

The current approach to reducing blood transfusion during major surgery can be broadly divided into methods that decrease operative blood loss and methods that provide autologous red cells. The methods that reduce blood loss include: deliberate hypotension; the injection of local vasoconstrictive agents at the operative site; and systemic pharmacologic agents for reducing blood loss, such as aprotinin, aminocaproic acid, tranexamic acid and desmopressin. Autologous red cells can be obtained either prior to the operation or during the operation. Autologous preoperative donation via a blood bank or acute normovolemic hemodilution are two techniques that are used prior to the operation to obtain autologous blood. Cell scavenging provides autologous red cells by scavenging blood from the operative field. These strategies may be used in combination during the operation to reduce or eliminate the need for allogeneic transfusion.
Acute normovolemic hemodilution (ANH) reduces red cells lost during the operation by decreasing the patient’s red cell mass immediately prior to operation [6, 9, 11, 13]. The first step in ANH is the acute, controlled removal of whole blood. The patient’s intravascular volume is maintained with non-red-cell-containing solutions during the phlebotomy. The operative procedure is conducted in a hemodiluted patient. During the operation, fewer red cells (as well as formed elements) are lost because the patient’s hematocrit is lower throughout the procedure. The autologous blood is reinfused at the conclusion of the operation. If the volume of red cells stored prior to operation is adequate and the operative blood loss does not result in profound red cell losses, then an acceptable hematocrit may be achieved without the use of allogeneic transfusion. While the amount of surgical blood loss is not appreciably changed by the use of hemodilution, fewer red cells will be lost due to the patient’s acute anemia.

Critical red cell mass

One of the key concepts in applying hemodilution is to define a patient’s “safe” lower limit for hematocrit [3, 10]. Healthy patients have a considerable usual reserve of red cells. This reserve is the principle reason that the acute removal of blood in the preoperative period is a viable therapeutic option. In ANH, patients experience two sources of red cell loss, the blood loss associated with hemodilution and operative blood loss. For this reason, a relatively profound anemia is expected during the operative procedure. Although the acute anemia associated with hemodilution is considerably different from anemia observed in clinical practice, the lowest safe red cell mass defined for anemic patients can be applied to guide acute normovolemic hemodilution. An abundance of case reports indicate patients can survive with extremely low hematocrits, but these anecdotal case reports are unlikely to provide a consistent “safe” lower limit of hematocrit [15].

The safe lower limit of hematocrit continues to be debated, yet an appreciation of the factors that define the lower limit of safety for red cell mass is an important consideration in implementing a hemodilution program. Critical red cell mass is the lower limit of hemoglobin associated with effective oxygen delivery. When cardiorespiratory compensatory mechanisms can no longer maintain effective oxygen delivery, a critical red cell mass exists. Anaerobic metabolism and/or tissue ischemia will occur when the red cell mass remains below this critical level. The critical red cell mass is reached first in tissue groups such as the myocardium and central nervous system, because a greater proportion of oxygen extraction occurs in the coronary or cerebral circulation under normal circumstances. The myocardium is particularly sensitive to decreased oxygen availability, because systemic compensatory responses to reduced red cell mass increase cardiac output. This higher cardiac output leads to increased myocardial work and heightened myocardial oxygen requirements. The increased cardiac energy expenditure puts additional demands on myocardial oxygen reserve at a time when oxygen supply is limited due to anemia. At hematocrits less than 20%, myocardial metabolism may be compromised by the decreased supply and heightened oxygen demand. Subendocardial ischemia and myocardial infarction can occur in healthy patients with normal coronary arteries when hematocrits are less than 15%. These changes are often manifested by EKG changes with ST segment elevation. In the liver and kidneys, centrilobular hepatic necrosis and acute renal failure may occur when hematocrits are sustained at hematocrit levels less than 15%.

Hemodilution to relatively low hematocrits may be better tolerated, because the period of anemia is brief and oxygen requirements are reduced by anesthesia. For this reason, hematocrit values of less than 20% are often recorded in a hemodiluted patient during the intraoperative period. If blood loss is replaced with crystalloid and replacement is withheld until a hematocrit of 20% is observed, then more than one-half of a patient’s blood volume could be removed by a combination of hemodilution and operative blood loss prior to replacing red cells.

Factors determining efficacy of hemodilution:

1. Red cell mass. Patients with greater red cell masses can donate more blood. Red cell mass is based on hematocrit and blood volume.
   a) Initial hematocrit: Patients with higher hematocrits are able to provide more red cells for storage prior to the operation. The patient’s beginning hematocrit and blood volume are key factors in estimating the amount of blood that should be removed prior to surgery.
   b) Blood volume. Blood volume increases with weight. The “ideal” 70-kg male has approximately a 5-l blood volume. Females have a slightly lower blood volume on a weight basis. For example, a 55-kg, adolescent female’s blood volume would be approximately 3,500 ml (55 kg × 60–65 ml/kg).

2. Magnitude of hemodilution. When lower hematocrits are achieved following hemodilution, less red cell loss will occur as a result of surgical blood loss. For this reason, the more blood removed prior to the operation the greater potential efficacy in reducing red cell losses. However, at the same time, this hemodilution leads to more profound hemodynamic consequences. If more blood is removed, the operative hematocrit will be lower, and, consequently, fewer red cells will be lost during surgical dissection. For example, a profound hemodilution (four units of whole blood in a 70-kg healthy patient) requires the administration of large volumes of non-red-cell-containing solutions to main-