Blood Conservation in Cardiac Surgery

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All bleeding stops eventually.

—from “The House of God” by Samuel Shem

Key Points

• Complications associated with blood product transfusions
• Risk factors for blood transfusions in cardiac surgery
• Preoperative strategies to decrease blood product transfusion need
• Intraoperative strategies to minimize blood transfusions
• Postoperative strategies to decrease blood product use in cardiac surgery

Introduction

Blood product transfusions are an important perioperative tool to prevent anemia-related tissue hypoxia as well as to correct coagulopathy and prevent further bleeding. However, despite reduction in the direct harm associated with transfusions (infection, leukoreduction), there is growing evidence concerning the indirect effects associated with higher morbidity and mortality. Cardiac surgery disproportionately consumes more blood products than any other field of medicine, accounting for 20% of total US blood transfusions (Fig. 15.1).

Approximately half of all cardiac surgeries result in transfusion. Furthermore, the observation of wide discrepancies in transfusion rates among cardiac surgical centers has highlighted the need for uniform modern blood conservation guidelines.
Implementation of blood conservation strategies has been shown to decrease transfusion rates, improve outcomes, and reduce costs.

### Complications

#### Infection

The risk of direct infection from blood transfusion has been dramatically reduced since the 1980s due to advances in donor screening and pre-transfusion blood testing. However, public stigma of transfusion-related infection often lags behind these advances in transfusion safety. It is therefore helpful to inform, and therefore comfort patients with up-to-date infection risk (see Table 15.1). While donor screening and blood testing have led to large reductions in infection transmission from donor to recipient, microbial contamination during the donation and storage process represents a more durable challenge. Transfusion-associated sepsis (TAS) accounts for approximately 10% of allogeneic blood transfusion (ABT)-related deaths in the United States. Of these, platelets account for 70% of TAS-related deaths, largely in part due to the relatively high storage temperature of 22 degrees Celsius, and product exposure to more venipunctures in the setting of pooled donor platelets.

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**Table 15.1** Infection risk associated with blood transfusion

| Estimated risk of infection by direct transmission from blood transfusion |  |
| --- | --- |
| HIV | 1 in 1.8 million |
| Hepatitis B virus | 1 in 220,000 |
| Hepatitis C virus | 1 in 1.6 million |
| HTLV-1 | 1 in 640,000 |
| West Nile virus | 1 in >1 million |

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**Fig. 15.1** Image of an example of cardiac surgery that consumed significant amount of blood products
**TRALI**

Transfusion-related acute lung injury (TRALI) is the leading cause of ABT-related death. The clinical signs and symptoms mimic adult respiratory distress syndrome (ARDS), but TRALI occurs within 6 hours of ABT. The pulmonary infiltrates seen in TRALI are caused by increased vascular permeability and occur in the absence of left atrial hypertension. Fresh frozen plasma (FFP) is the most frequently implicated component. The case-fatality ratio in TRALI is 5–10%. Treatment is largely supportive with 70% of cases requiring mechanical ventilation and rarely the use of veno-venous extracorporeal membrane oxygenation (VV-ECMO).

**TACO**

Transfusion-associated cardiac overload (TACO) presents with clinical features similar to TRALI but differs in the mechanism and treatment. In TACO, pulmonary infiltrates develop due to increased hydrostatic pressure secondary to volume overload. Physical exam, echocardiography, BNP serum levels, and response to diuretics are often helpful in differentiating TACO from TRALI.

**Transfusion-Related Immunomodulation (TRIM)**

ABT suppresses recipient cell-mediated immunity and has been associated with a dose-dependent increase in the risk of postoperative infection. While the exact mechanism is unclear, it is commonly hypothesized that donor WBCs present in ABT are the cause of TRIM. This hypothesis has been tested numerous times in studies comparing leukoreduced blood products to WBC-containing products, with mixed results in mortality and infection risk. There is proven benefit to leukoreduction in decreasing the incidence of non-hemolytic febrile transfusion reactions and CMV transmission. As blood banks trend towards using universally leukoreduced blood products, it has become much harder to conduct appropriately powered clinical trials comparing leukoreduced blood products to leukocyte-containing products.

**Predictors of Perioperative Bleeding or Transfusion**

There are many factors that can predict the risk of perioperative bleeding necessitating transfusion in cardiac surgery: age >75, female gender, low body surface area (BSA), preoperative anemia or thrombocytopenia, anticoagulation, antiplatelet medications, coagulopathy, Cr >1.3, combined CABG and valve surgery, emergency surgery, preoperative shock state or use of intra-aortic balloon pump, and prolonged duration of cardiopulmonary bypass (CPB).
Preoperative Strategies

Preoperative Anemia

Perioperative blood conservation starts with preoperative anemia screening and treatment when the operative timeline allows. Preoperative anemia correction and medical optimization is discussed in Chap. 7.

Autologous Donation

Preoperative autologous blood donation decreases ABT but increases total transfusion rate (including autologous donation). The challenge of this technique is allowing the patient enough time for hematopoietic recovery without losing donated blood quality through aging. While autologous donation has been shown to have a low cost-effectiveness in the general population, it is especially helpful in the non-anemic patient who has a rare blood type, difficult crossmatch, Jehovah’s Witness, or in times of blood shortage. Contraindications for autologous donation include unstable angina and aortic stenosis, which affects a significant proportion of cardiac surgery patients.

Intraoperative Strategies

Acute Normovolemic Hemodilution (ANH)

ANH is the collection of autologous whole blood after induction of general anesthesia, with concurrent IV hydration to maintain isovolemia. As a result, autologous units are sequentially more dilute due to the ongoing hemodilution. ANH reduces hematocrit so that less RBC mass is lost during surgical bleeding. Autologous blood is reinfused, as needed, in reverse order of collection. This allows for the most concentrated unit to be transfused during the period of least blood loss (Fig. 15.2). ANH is a low-cost procedure that is relatively simple to perform and can easily be combined with other techniques like preoperative autologous donation and cell salvage. ANH has been shown to decrease exposure to ABT, and is especially suited for patients with high preoperative hemoglobin levels who are expected to experience significant blood loss.

Antifibrinolytics

Antifibrinolytic agents have been shown to decrease blood loss and transfusion rates in cardiac surgery. The commonly used agents are tranexamic acid (TXA) and aminocaproic acid (ACA). Aprotinin, another slightly more hemostatic antifibrinolytic, lost FDA approval, in 2008, after a single trial demonstrated increased mortality with its use. These agents are discussed in detail in the pharmacological blood conservation section of Chap. 3. The Society of Thoracic Surgeons (STS) and the
Society of Cardiovascular Anesthesiologists (SCA) recommend the routine use of antifibrinolytics during cardiac surgery.

**Surgical Factors**

There are many surgical factors that influence the quantity of blood loss and ABT in cardiac surgery. The avoidance of cardiopulmonary bypass-related hemodilution and coagulopathy with surgical techniques such as off-pump CABG has been shown to reduce perioperative bleeding and ABT. Additionally, the blood loss associated with median sternotomy can be reduced with minimally invasive (MI) surgical approaches, namely, parasternal or mini-thoracotomy approaches for CABG and robotic mitral valve surgery.

**Fig. 15.2** Acute normovolemic hemodilution. (a) Phases of ANH during surgery. (b) ANH citrate collection bag/tubing. (c) Whole blood collection during ANH
Cardiopulmonary Bypass (CPB) Factors

The CPB machine ushered in the era of modern cardiac surgery, but with this essential tool come the undesired side effects of hemodilution and platelet dysfunction. Over time, these problems have been reduced, but not eliminated, by various optimizations of the CPB machine.

Retrograde autologous priming (RAP) involves replacing a portion of the CPB crystalloid-based priming volume with 400–800 mL of the patient’s own blood. This reduces the CPB-related hemodilution, improves end-organ perfusion while on CPB, and reduces ABT during cardiac surgery. RAP occurs just prior to initiating full CPB and typically takes 2–5 min. Vasopressors are often administered, during RAP, to maintain adequate mean arterial pressures (MAPs).

In addition to RAP, other features of the CPB machine have been optimized to aid in blood conservation. Centrifugal CPB pumps have largely replaced standard roller pumps due to their decreased shear force exerted on RBCs and subsequent hemolysis, as well as a reduction in particulate embolization from the breakdown of the circuit tubing. Drug-coated CPB circuits have shown modest benefits in reducing allogeneic RBC transfusion through decreased systemic anticoagulation requirements (heparin-coated) and postoperative bleeding (phosphorylcholine-coated). CPB circuit miniaturization can reduce priming volumes by as much as 1 L, resulting in less hemodilution and reduced rate of ABT.

Many of the physiologic and pharmacologic changes induced for CPB, namely, hypothermia and heparinization, need to be reversed after separating from bypass in order to promote hemostasis. Hypothermia can produce a profound coagulopathy functionally equivalent to clotting factor-deficient states, despite normal factor levels. It is therefore important to achieve normothermia during the post-CPB phase of cardiac surgery in order to optimize hemostasis and prevent unnecessary ABT. Likewise, the heparinization required for CPB is reversed with protamine after separation from CPB. Protamine, when given alone or in disproportion to heparin levels, acts as an anticoagulant so it is important to avoid overdosing. There is some suggestion in the literature that protamine dosing to serum heparin level is more appropriate than blindly dosing to a fixed 1:1 ratio of the original dose of heparin, as some heparin is metabolized and/or lost to the CPB circuit, resulting in protamine overdose, preventable coagulopathy, and bleeding.

Cell Salvage

Cell saver is a cell salvage technique involving the collection, washing, and centrifugation of recovered blood. Autologous cell saver transfusion can reduce ABT, but the majority of the clotting factors and platelets are lost during centrifugation. The resultant RBC predominant autotransfusion can predispose to and perpetuate coagulopathic bleeding in some patients. Despite this pitfall, the net benefit of reduced ABT exposure was confirmed in a recent meta-analysis leading the STS/SCA to make cell salvage use a Class 1A recommendation during cardiac surgery.
Ultrafiltration is a newer form of cell salvage in which salvaged blood is exposed to a polycarbonate superadsorber capable of withdrawing plasma but holds the unique advantage of preserving all cell species. Once hemoconcentrated, the salvaged blood is transfused back to the patient as needed.

**Point of Care Testing**

CPB confers a number of unique challenges related to blood conservation. Rapid heparinization, under- or over-reversal with protamine, hemodilution, prolonged contact with CPB circuit tubing, shear stress of CPB pump, reduced coagulation factors, hyperfibrinolysis, and platelet dysfunction and consumption all contribute to CPB-related coagulopathy and anemia, increasing the use of allogeneic blood products.

Current pre- and postoperative practice involves using laboratory-based assays (platelet count, fibrinogen, Prothrombin Time (PT)/ International Normalized Ratio (INR), Partial Thromboplastin Time (PTT)) to characterize and treat coagulopathic bleeding in the nonoperative setting. However, standard laboratory-based assay turnaround is often too slow to guide intraoperative blood management. While the experienced anesthesiologist and surgeon may be able to identify the signs of microvascular bleeding in the surgical field and initiate early empiric treatment, subjective assessment will often lead to over- or undertreatment of coagulopathic bleeding. Point of care (POC) testing offers a quicker turnaround leading to more timely targeted therapies. POC glucose, hemoglobin, activated clotting time (ACT), and blood gas analysis are routinely used in cardiac surgery, but the introduction of POC viscoelastic testing (thromboelastography (TEG) or rotational thromboelastometry (ROTEM)) offers rapid assessment of clotting time, thrombocytopenia, hypofibrinogenemia, and fibrinolysis. During critical portions of cardiac surgery, this quick evaluation can guide the appropriate intervention in the form of transfusion, pharmacotherapy, or surgical revision. POC viscoelastic testing has been shown to reduce the exposure to allogeneic blood products, postoperative blood loss, and even ICU length of stay.

**Restrictive Transfusion Strategy**

Previously, little high-quality evidence existed to guide intraoperative transfusion strategy, resulting in a wide variability in rate of ABT among cardiac surgery centers. Accumulating evidence has challenged the prevailing view that any perioperative anemia is associated with increased morbidity by demonstrating the dose-dependent risk of ABT.

Restrictive RBC transfusion strategy (Hgb <7.5 g/dL intra- and postoperatively) has recently been shown to be non-inferior compared to liberal transfusion strategy (<9.5 g/dL intraoperatively and 8.5 g/dL postoperatively), with respect to mortality at 28 days and 6 months, as well as major comorbidities (MI, stroke, and renal failure requiring dialysis). Rate of transfusion decreased approximately 20% when employing the restrictive transfusion thresholds. It is important to note that the
safety of permissive anemia has not been validated in patients with acute coronary syndrome (ACS), a significant subpopulation in cardiac surgery.

Figure 15.3 summarizes multimodal blood conservation strategy.

Further Readings

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