INTRODUCTION

Errors in pretransfusion specimen collection, omission of appropriate transfusion filters, or co-administration of incompatible fluids with blood products could transform blood transfusion from a lifesaving measure into a life threatening event. In this chapter, we will summarize key aspects of blood component administration, with an emphasis on processes and technologic advances that promise to improve the quality of patient care and patient safety. The paragraphs below are only general guidance based on current guidelines and regulations. In addition to this information, the reader is directed the latest version of the AABB Standards, local standards of practice, and institutional requirements.

Pretransfusion considerations

Prior to transfusion, there are several steps that should be taken to ensure that patient safety is protected. First, unless the request for blood is emergent, it is essential to obtain informed consent for blood transfusion. Per the AABB Standard (5.26.1.1), at minimum, informed consent requires the inclusion of the following: (1) a description of the risks, benefits, and alternatives (including non-treatment); (2) the opportunity to ask questions; and (3) the right to accept or refuse transfusion.1 In some parts of the United States, there is also a legal requirement (e.g., the Paul Gann Blood Safety Act in California) to discuss alternatives to transfusion. Furthermore, it is recommended that this discussion between healthcare provider and patient be properly documented.2,3

Second, unless the indication for transfusion is emergent, pretransfusion compatibility testing should be performed prior to component issue. Determining a transfusion recipient’s blood type and identifying whether any unexpected antibodies are present in the recipient’s plasma can prevent hemolytic transfusion reactions and conserve limited resources (e.g., group O RBCs and group AB plasma).4 To begin the pretransfusion compatibility testing process, the clinical staff must obtain a blood sample from a correctly identified patient. The specimen should be labeled with a minimum of two patient identifiers (e.g., name and date of birth), the date of the blood draw, and the identification of the person who drew the blood (e.g., phlebotomist initials). Samples can be rejected by the blood bank if they are improperly labeled, if the requisition form is missing key identifying information, or if the sample was drawn in the incorrect tube.5–7 Studies have consistently shown that human errors throughout the pretransfusion process occur at substantial rates and can lead to fatal incompatible transfusions.5–7

VENIPUNCTURE FOR INTRAVENOUS (IV) ACCESS

Blood components are most often transfused intravenously through peripheral veins, but central venous access can also be used in critically ill patients.8 A previously established IV line can be used for blood transfusion. However, prior to use, the line should always be examined for patency and signs of infection. Ideally, the line should be flushed with normal saline to ensure that any incompatible fluid is removed prior to blood component infusion. The line should also be of sufficient bore to prevent hemolysis.

COMPONENT ISSUE, RELEASE, STORAGE, AND TRANSPORT

COMPONENT ISSUE AND RELEASE

Before a component is issued from the blood bank, safeguards should be established to ensure that the correct component is released to the intended patient. The verification process between the blood bank laboratory technologist and the transportation courier includes checks of donor and recipient identifying information as well as ABO group and Rh type, expiration date of the unit, crossmatch results, satisfaction of any special transfusion requirements (e.g., irradiated or washed), and a check for any visual abnormalities of the unit.1 Once this checklist is complete, the date and time of issue should be noted, and the component can then be taken to the patient’s bedside.

COMPONENT STORAGE

Blood bank storage devices include freezers, refrigerators, and platelet incubators. Maintaining proper component storage and equipment monitoring systems is critical to protect the quality of blood products. All storage devices must also be equipped with an emergency power supply and a continuous alarm monitoring system. In the absence of such a system, the temperature must be monitored and documented every four hours. Alarms should continue to function even in the event of a power failure. Scheduled alarm checks should occur at least quarterly.9

RED BLOOD CELLS (RBCS)

RBCs must be stored within refrigerators in the blood bank and continuously maintained at 1–6 °C to limit their metabolic activity while ensuring cell viability.10 During the transport process, warming of blood a few degrees (up to 10 °C) is acceptable. Historically, studies have demonstrated that RBC units change temperature quickly when
removed from refrigeration and that this temperature increase can affect the cellular viability of the component. These findings led to the so-called 30-minute rule, whereby blood stored outside of the recommended storage temperatures for greater than 30 minutes could not be placed back into the blood bank inventory. However, current studies have questioned the validity of this rule. According to the 2014 CAP (the College of American Pathologists) checklist (TRM.42470), blood components can be reintroduced into the inventory if the unit has not exceeded 10°C and if steps have been taken to “verify the integrity and appearance of the container.”

**Platelets**

Current AABB Standards recommend platelet storage at room temperature (20–24°C) with continuous gentle agitation. Room temperature storage is favored because platelets stored at 20–24°C have good posttransfusion in vivo recovery, and exposure to cold temperature storage is favored because platelets stored at 20–24°C and refrigerated to room temperature (20°C) with continuous gentle agitation. These changes in regulations seen in the AABB Standards in 2004 introduced a requirement to limit and detect bacterially contaminated platelet components in an effort to mitigate this potential hazard.

Platelets are sensitive to pH changes and must be adequately agitated. Importantly, platelet agitation promotes gas exchange through the plastic storage container, helping to effectively maintain pH. Platelet agitation devices have been extensively studied. Results of these studies show that horizontal agitation (circular or flatbed agitators moving side to side) maintain platelet functionality better than do more vigorous, vertical (end over end) methods of agitation. Studies have also demonstrated that deleterious effects on platelet components can begin to take place after one day or longer of interrupted agitation. Accordingly, AABB Standards permit a maximum 24-hour period during product transport when platelets do not need to be agitated.

**Plasma**

There are several different preparations of plasma that are differentiated based on the manner and timing of the plasma separation and freezing processes. The most familiar product for many blood centers is fresh frozen plasma (FFP), which is separated from whole blood and placed in a freezer within eight hours of collection. Generally, if plasma is frozen within 24 hours of collection, it can be labeled either as plasma frozen within 24 hours (PF24) or plasma frozen within 24 hours after phlebotomy held at room temperature up to 24 hours after phlebotomy (PF24RT24), although specific manufacturing requirements must be met in order to qualify for these labels. FFP, PF24 and PF24RT24 can generally be maintained in a freezer at ≤–18°C for 12 months after collection. Plasma that is separated from whole blood and is never frozen can be labeled as liquid plasma, which expires five days after the whole blood from which it was derived. These variations in labeling are due to concern that plasma that is not separated and frozen within eight hours could have diminished levels of coagulation factors.

After thawing, FFP should subsequently be stored at 1–6°C. Temperatures up to 10°C are acceptable during transport. If the component is not transfused within 24 hours, it can be relabeled as thawed plasma and stored in a refrigerator for an additional four days. Trauma centers, which treat patients emergently requiring plasma transfusion, may use some thawed plasma units in order to avoid wasting FFP that has already been thawed, as well as to avoid delays in the provision of plasma due to the time required for thawing. Outside of the United States, there is limited availability of freeze-dried plasma, which has a 15–24-month shelf life and can be reconstituted in 5–10 minutes.

**Cryoprecipitate**

Cryoprecipitate is derived from FFP thawed slowly in an ice bath or in a refrigerator at 1–6°C. At this low temperature, insoluble cryoprecipitable proteins can be collected by centrifugation, and all but 10–15 mL of the thawed plasma is removed and relabeled as cryoprecipitate-reduced plasma. The remaining 10–15 mL of plasma and insoluble precipitate is labeled cryoprecipitate. According to current AABB Standards, cryoprecipitate must contain at least 150 mg of fibrinogen and a factor VIII activity level of 80 IU. This component also contains other plasma proteins, including fibronectin, factor XIII, and von Willebrand factor. Cryoprecipitate, once collected from thawed FFP, must be frozen within one hour and can be maintained at ≤–18°C for up to 12 months. When the product is requested for clinical use, it should be thawed at 30–37°C, and then stored and transported at room temperature to prevent re-precipitation of the component. A pooled component expires within four hours unless the pooling occurred with the use of a sterile connection device. In this case, and in the case of single pools, the product shelf life is extended to six hours.

**Granulocytes**

Although controversial, septic patients with severe neutropenia may require transfusion with granulocytes. From a blood component administration perspective, granulocytes must be irradiated and infused within 24 hours of collection. Because the RBC content of a granulocyte collection usually exceeds 2% (typically approximately 6%), granulocyte products must also be ABO and crossmatch-compatible with the recipient. Granulocytes should be maintained at room temperature without agitation and must never be leukoreduced.

**Hematopoietic progenitor cells**

Once infused, hematopoietic progenitor cells are intended to engraft in the recipient’s bone marrow. For this reason, infused hematopoietic progenitor cells must never be irradiated. In an effort to minimize prevent hematopoietic progenitor cell loss, many transplant centers infuse hematopoietic stem cells into the recipient without the use of a standard infusion set, a microaggregate filter, or a leukoreduction filter. After infusion, sterile saline may be injected into the empty stem cell container to rinse the bag in an effort to maximize stem cell recovery. Specific standards for cellular therapy products are established and maintained by the US Food and Drug Administration (FDA; www.fda.gov), AABB (www.aabb.org), CAP (www.cap.org), and the Foundation for the Accreditation of Cellular Therapy (FACT; www.factwebsite.org).

**Prothrombin complex concentrates and recombinant clotting factors**

Some transfusion services are responsible for dispensing prothrombin complex concentrates (PCCs) and recombinant clotting factors, which are increasingly utilized in patients with uncontrolled bleeding. These products are often lyophilized and must be reconstituted with sterile water or another diluent prior to infusion. Administration of these drugs should always be in compliance with the package insert. In general, recombinant factors can be administered by a slow intravenous push, whereas multifactor pooled plasma products (e.g., factor VIII inhibitor bypassing agent [FEIBA])
and the four-factor PCC) must be administered much more slowly. For hospitals that regularly infuse FEIBA or four-factor PCC, use of a syringe pump or infusion pump can help to ensure that the product is administered safely and at the recommended rate.

**Storage equipment**
Automated equipment for blood component storage includes refrigerators, freezers, cell washers, platelet agitators, and plasma thawing devices. One example of new equipment for blood storage is the Hemosafe refrigeration system (Haemonetics Corp, Braintree, MA). The Hemosafe device maintains a temperature of 4°C and acts as a “vending machine” for RBC units, allowing them to be stored and dispensed remotely. Hemosafe’s computer system interfaces with that of the hospital’s blood bank and relies on an electronic crossmatch to issue compatible blood to patients. If a particular patient cannot receive an electronically crossmatched unit, the system also allows for the emergency release of uncrossmatched blood. A similar system, the HemoNine (Haemonetics Corp, Braintree, MA), contains nine locking drawers, one for each blood type–Rh type combination, plus one additional drawer for crossmatched RBC units. The utility of these systems in hospitals of varying sizes is still undergoing evaluation.

**Component transport**
Considerations for component transportation are critical to maintaining the integrity of the component to be transfused. Many medical centers rely on validated portable containers or coolers to transport blood products in order to maintain RBC and plasma temperatures below 10°C. These coolers should have the capability of being temperature monitored at least every four hours with the expectation that the transfusion should occur quickly and before substantial temperature shifts have taken place.1 Temperature-sensitive adhesive labels that attach directly to the component or the containers can also be used to monitor transport temperatures. These labels have indicators that change color when the temperature limit is exceeded.26 Therefore, when a blood component is not transfused, either the label can be checked for a color change or the temperature of the unit can be taken to determine whether it can be safely returned to the blood bank inventory.9

**Novel transport and storage devices**
Portable refrigerator technology has improved with some portable refrigerators being capable of maintaining a refrigerated temperature for up to 24 hours after leaving the blood bank. Some models incorporate tracking devices, so that the location of the cooler can be tracked by the blood bank at all times. In addition, some coolers maintain a temperature log during use. These types of technologies have the potential to increase cost savings and limit product waste, but they require a substantial capital investment. However, more studies are needed to evaluate these devices and their utility before widespread implementation is likely.

**Component modification and preparation**
When ordering blood components, physicians should also stipulate any specific product modification requirements. Leukoreduction, washing, irradiation, and volume reduction are common component manipulations that take place in the blood bank to enhance safety for special populations. As these component modifications often influence the expiration date of the component, the time of outdate must be noted as well.

**Leukoreduction**
Prestorage leukoreduction, the process of removing leukocytes from whole blood prior to storage, is utilized to prevent the transfusion-mediated transmission of cytomegalovirus (CMV),29 human leukocyte antigen (HLA) alloimmunization,30 platelet refractoriness,31 and febrile nonhemolytic transfusion reactions.32 Importantly, certain blood components, such as granulocytes and hematopoietic progenitor cells, must never be processed through a leukoreduction filter (Table 3.1).26 Leukoreduction filters, which work by interception and adhesion of white blood cells to fiber media, should not be confused with the 170–260 micron screen filters incorporated into standard blood administration tubing sets. These screen filters work by clot or debris interception and are used for all blood component infusions (see Table 3.1). The 40 micron microaggregate filters, which also work by interception, are used in cell salvage devices.

In the United States, leukoreduction of units of RBCs requires removal of leukocytes to less than $5.0 \times 10^6$ leukocytes/unit. Notably, this requirement is less stringent than current European requirements, which stipulate that less than $1 \times 10^6$ leukocytes should remain.14,33 There is a clear move toward universal leukoreduction in the United States, and the FDA advisory committee specifically recommended leukoreduction in 2001. According to 2011 estimates, only 70.5% of whole blood–derived RBCs and 80.1% of apheresis platelets transfused in the United States were leukoreduced.34 The American Red Cross, which supplies ~50% of the US blood needs, does report universal leukoreduction of blood components manufactured in their facilities.35 However, because leukoreduction policies differ by blood bank and blood supplier, it is

<table>
<thead>
<tr>
<th>Component</th>
<th>Transfuse through Standard Transfusion Set and filter?</th>
<th>Need for Leukoreduction?</th>
<th>Need for Irradiation?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red blood cells</td>
<td>Always</td>
<td>Desirable—to reduce risk of CMV transmission,</td>
<td>Yes, to prevent TA-GVHD in vulnerable populations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>febrile nonhemolytic transfusion reactions, platelet refractoriness, and HLA alloimmunization</td>
<td></td>
</tr>
<tr>
<td>Platelets</td>
<td>Always</td>
<td>Desirable—to reduce risk of CMV transmission,</td>
<td>Yes, to prevent TA-GVHD in vulnerable populations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>febrile nonhemolytic transfusion reactions, platelet refractoriness, and HLA alloimmunization</td>
<td></td>
</tr>
<tr>
<td>Plasma</td>
<td>Always</td>
<td>Not applicable</td>
<td>No</td>
</tr>
<tr>
<td>Cryoprecipitate</td>
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<td>Not applicable</td>
<td>No</td>
</tr>
<tr>
<td>Granulocytes</td>
<td>Always</td>
<td>Never</td>
<td>Always, to prevent TA-GVHD</td>
</tr>
<tr>
<td>Hematopoietic precursor cells</td>
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<td>Never</td>
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</tr>
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</table>
important for healthcare providers to be aware of their hospital-based practices.

Irradiation
Irradiation of cellular blood components (i.e., granulocytes, platelets, and RBCs) is necessary when transfusing patients determined to be at high risk for transfusion-associated graft-versus-host disease (TA-GVHD). Irradiation of donor units is also performed when the blood donor is known to be a blood relative or an HLA match with the recipient. Ensuring proper irradiation is especially critical because there is no known effective treatment of TA-GVHD, which is generally fatal. To prevent TA-GVHD, a radiation dose of 25 Gy (2500 cGy/rads) directed at the central portion of the blood canister, with no less than 15 Gy to any part of the canister is required in the US. This dose of irradiation damages the DNA of T cells contained within the cellular blood component, thereby preventing T-cell engraftment and TA-GVHD. The irradiation of noncellular blood components, such as plasma and cryoprecipitate, is not required.

The source of radiation used by blood banks is typically $^{137}$Cs, $^{60}$Co, an X-ray generator, or a linear accelerator. Irradiators that utilize $^{137}$Cs or $^{60}$Co contain the isotope within chambers made of lead to prevent escape of $\gamma$ rays from the irradiation device. Typically, $^{137}$Cs irradiators contain 1–4 pencil-shaped rods of cesium and a rotating platform or cylinder. During irradiation of blood products, the blood component is placed on the rotating platform to ensure an even dose of radiation to the unit. In contrast, $^{60}$Co irradiators usually contain rods of cobalt arranged in a circular configuration, and do not generally utilize a rotating platform. Linear accelerator irradiators generate a beam of X-rays, allowing blood components being irradiated to lay flat during the irradiation procedure. An X-ray tube generating device can also be used. All of these types of irradiators require periodic maintenance and quality assurance programs, and irradiators using $^{137}$Cs or $^{60}$Co must periodically be recalibrated to account for the gradual radioactive decay of the radioactive isotopes. The US government is reviewing the possibility of eliminating hospital or blood center irradiators that use $^{137}$Cs or $^{60}$Co and replacing them with X-ray tube devices that pose less of a target for bioterrorism.

Regardless of the source, irradiation reduces the expiration date of RBCs to 28 days from the date of irradiation or the original expiration date, whichever is sooner. Irradiation, however, does not alter the expiration date or the function of platelets, and as a result, some hospitals with large oncology wards irradiate all platelets at the time that they are placed in hospital inventory. Special radiographic indicator labels are recommended in order to confirm that an irradiated blood component has received an appropriate dose of radiation.

Washing
The washing process for RBCs or platelets is usually performed with isotonic saline in an automated, centrifuge-based machine housed in the blood bank or blood center. Once the RBCs or platelets are centrifuged into a “packed” state, isotonic saline flows through the packed, cellular mass, washing out the plasma and preservative solution, and replacing it with isotonic saline. There should be a clear clinical indication for cell washing, as the automated washing process can result in loss of as much as 20% of the RBCs or platelets being washed. Furthermore, cells are generally washed in an open system, and as a result, RBCs expire 24 hours after washing and platelets expire four hours after washing, regardless of the original product expiration dates. Some washing devices may induce more RBC destruction during the washing process than others, resulting in higher supernatant potassium levels. For these reasons, washing RBCs and platelets immediately prior to use is preferred.

Volume reduction via aliquoting
In an effort to prevent transfusion-associated circulatory overload (TACO) in at-risk patients, RBC, platelet, and plasma units can be split into smaller aliquots using transfer bags and a sterile connecting device. Sterile connecting devices work by connecting sterile tubing segments with copper wafers heated to more than 500°F, melting the plastic tubing and juxtaposing the severed ends together. The heating process prevents bacterial contamination. As long as the system remains closed throughout the process, the shelf life of the transfer bag will remain the same as the shelf life of the primary unit. Similar technology is employed by heat sealers, which melt plastic tubing and generate a seal that can be detached without opening the blood component.

For neonates requiring very small transfusion volumes (sometimes as little as 10–30 mL), aliquoting of cellular components into a syringe with a connecting device can help to maintain an aseptic environment, and can preserve the remainder of the blood component, which can be stored properly in the blood bank, for future transfusions. Because transferring to a syringe is not generally performed within a closed system, blood components transferred to syringes must also be transfused to the recipient within four hours or be discarded.

Thawing plasma
Compared to warming procedures for other blood components, plasma thawing is relatively complex. FFP and PF24 are stored at −18°C or below, and can take 20–30 minutes to thaw in a 37°C water bath. Microwave ovens are more expensive than water baths, but may be more suitable for urgent plasma requests. Indeed, specially designed microwave ovens have been shown to thaw components more quickly, in approximately 5–10 minutes, without affecting the function of the coagulation proteins in the plasma. Unlike microwave ovens, 37°C water baths have the potential to introduce bacterial contamination into the component if the component is not properly sealed and protected in a waterproof bag. Water-based warmers, which circulate warm water through a plastic attachment inserted next to the plasma bag rather than requiring the plasma bag to be submerged in the water bath, may also protect against this risk.

Although both water baths and microwave ovens must be properly maintained, microwave ovens have the added risk of damaging the component plasma proteins in the event of malfunction or the development of “hot spots.” Indeed, some experiments with early microwave ovens identified areas of overheating within the plasma bag, such as at the junction where the tubing segment connects to the bag. More recent experiments with specially designed microwave blood warmers have not identified overheating during normal function. Nonetheless, it appears that the state of the art may be moving away from microwave technology and toward radiofrequency-based thawing, which uses longer wavelengths to achieve a more uniform distribution of energy, thus minimizing temperature gradients within the plasma during rapid warming.
At the bedside: transfusion administration

Pretransfusion
Once a blood product that has been modified as necessary is issued by the blood bank and reaches the patient’s bedside, the next step is to ensure that the transfusion recipient is properly identified. The transfusionist as well as a second person must verify pertinent information before the transfusion is initiated. Required elements of the process include identification of the patient by two unique identifiers as well as confirmation of the patient’s blood group and Rh type. Similarly, the donor unit should be crosschecked for ABO group and Rh type. The results of the crossmatch, any special component modifications, and the expiration date of the component must also be reviewed. Before the transfusion begins, there should be a documented set of pretransfusion vital signs e.g., (temperature, pulse, blood pressure, and oxygen saturation). If the patient experiences any clinical changes during the transfusion, these initial vital signs will serve as baseline values.

Blood administration sets and filters
Once blood components leave the blood bank, transfusion should be initiated as quickly as possible to avoid the risk of bacterial overgrowth. All blood component transfusions must be completed within four hours. Institution specific criteria should be followed, but Standard blood administration infusion sets are required for infusion of all blood products (except hematopoietic precursor cells). These sets consist of three main parts: inline filters, drip chambers, and tubing that can be attached directly to a previously established IV line. The inline filters of the administration sets have a 170–260 micron pore size and are responsible for removing large fibrin clots and cellular debris from all blood components immediately before they enter the patient. The filters should be used and replace according to manufacturers recommendations.

Historically, it was found that smaller aggregates of cellular debris and fibrin strands could also develop within stored blood. It was thought that these microaggregates played a role in the development of acute respiratory distress syndrome (ARDS), but a causal link was never established. Currently, microaggregate filters of 20–40 μm sizes are primarily used to transfuse autologous blood that has been salvaged from cardiac surgery procedures. Previously, leukoreduction filters were also available for bedside use, but with the trend toward universal prestorage leukoreduction, these filters are less frequently used at the bedside. The drip chamber is a standard component of the infusion set that allows the transfusionist to control the rate of infusion and serves to avoid infusion of air. Prior to use, the infusion set and tubing can be rinsed or primed with either 0.9% sodium chloride or the component to be transfused.

When the aliquoting technique is employed for small-volume infusions in neonates, as previously discussed in this chapter, a special syringe administration set is used. Typically, during the aliquoting procedure in the blood bank, the blood component is passed through a filter.

Co-administration of fluids and blood components
Considerations as to whether other IV solutions can be administered in parallel with a blood component through the same IV line are often raised. According to the AABB Standards, the only compatible fluid is 0.9% normal saline. However, allowances are made for FDA-approved drugs or solutions that have been shown to be isotonic and that do not contain enough calcium to neutralize the citrate anticoagulant in the blood component. Lactated Ringer’s solution and other solutions that contain high calcium concentrations should be avoided as they can cause clotting of the blood component if they overwhelm the ability of the citrate to effectively anticoagulate the product. Hypotonic or hypertonic solutions should be avoided because of the risk of osmotic hemolysis.

Co-administration of medications
Although this practice has not been extensively studied, in general, medications should not be administered simultaneously through the same IV line as the blood component. This is for several reasons, including the fact that, in the event of simultaneous administration of a blood component and a medication, it would be difficult to differentiate a reaction to the medication from a reaction to the blood component. In addition, if a transfusion needed to be stopped, then the patient may not receive the intended dose of the co-administered medication. Furthermore, some medications may not be compatible with the blood components and may cause hemolysis or clotting. For these reasons, it is best to use a separate IV line for medication administration. In the event that additional IV access has not been established, then the IV line used for the blood component should be clamped and flushed with 0.9% saline before infusing any medications. When blood components must be administered concomitantly, as in the setting of trauma or surgery, this can be accomplished with the use of separate IV lines. In emergent cases, multiple blood components (e.g., RBCs and plasma) can be transfused through the same tubing and IV line.

Patient monitoring
After the transfusion has begun, the patient’s vital signs should be evaluated and documented 15 minutes after the start of the transfusion. If the patient has any suspected adverse reactions, then the transfusion should be stopped until the patient can be clinically evaluated. Depending on the scenario, the transfusion may need to be discontinued altogether. If a patient has a mild allergic reaction (hives) without signs of vasomotor instability, laryngeal edema, or tongue or lip swelling, it is permissible to restart the transfusion if the symptoms resolve with antihistamine therapy. However, a transfusion should not be restarted if the recipient has a drop in blood pressure, fever, chills, an anaphylactic reaction as just described, or an increase in temperature (even if there was a preexisting fever). Symptoms of this type should trigger a transfusion reaction workup by the physician responsible for the transfusion, the blood bank and the blood bank consulting physician.

Infusion flow rates
Optimal infusion rates vary with the component being transfused and the patient’s ability to tolerate increased intravascular volume. Components should generally be infused slowly at first, and then the rate can be increased as tolerated by the patient. Patients at risk for volume overload, such as those with poor cardiac status, should receive a slow infusion rate with close monitoring, if feasible. In general, RBCs and plasma have volumes ranging from 200 to 400 mL and are typically infused over 1–2 hours. Platelets range in volume from 200 to 300 mL and are also generally infused over 1–2 hours. Cryoprecipitate can be given as rapidly as tolerated and should be infused as soon after the thawing procedure as is clinically acceptable.
There is a paucity of evidence to make specific recommendations regarding blood component flow rates in neonatal and pediatric patients. Although concern exists that increased rates can cause intraventricular hemorrhage or electrolyte imbalances in neonates, there is limited high quality evidence to support this theory. Therefore, in this patient population, for routine blood component administration, transfusions are usually administered over 2–4 hours.\(^\text{14}\) Recommended infusion rates range from 5 ml/kg/h (RBCs) to 10–20 ml/kg/h (platelets) and 15 ml/kg/h (plasma).\(^\text{47}\)

In certain clinical scenarios, there is a need to transfuse a unit of RBCs, plasma, or platelets at a slower rate than would allow for completion of a transfusion in a four-hour period. As mentioned in the “Volume Reduction via Aliquoting” section, one strategy to accomplish this relies on the blood bank’s ability to split units using a sterile tubing welder, so that half units can be issued to the patient, with the remaining sterile half unit properly stored in the blood bank. The transfusionist can administer the split unit over a four-hour period, and then contact the blood bank to request the other half of the unit. This practice allows for a unit of RBCs, plasma, or platelets to be divided and effectively infused over eight hours, or more.

**RBC salvage devices**

*RBC salvage* refers to the concept of reclaiming and processing blood lost in the surgical field for the purpose of autologous transfusion. There are two types of devices. One type of device works by combining blood salvaged from the surgical field with an anticoagulant solution. The blood–anticoagulant mixture is then fed into a storage chamber before being centrifuged, washed, and infused back into the patient through a microaggregate filter. These salvage devices, which incorporate a washing step, are usually confined to the operating room. Other salvage devices without a washing feature are intended for patients undergoing orthopedic surgery, and they also act as a surgical drain. These devices remain connected to the patient even after leaving the operating room. Salvage devices have been shown by some studies to reduce allogeneic RBC transfusions for both adult and pediatric patients undergoing cardiac surgery.\(^\text{40,49}\) Due to the minimum amount of blood loss needed for any of the RBC salvage devices to function effectively and due to their extracorporeal volume, these devices are not useful in children under six months of age.\(^\text{50}\)

**Rapid infusion practices**

Blood products are occasionally requested on an urgent basis when a patient is deemed to have a life-threatening condition that does not allow for sufficient time for a full crossmatch prior to blood component issue. Conspicuously labeled un-crossmatched units can be stored in blood bank–monitored refrigerators in critical areas throughout the hospital such as the emergency department, operating rooms, labor and delivery suites, and intensive care units. Most hospitals reserve Rh-negative units for women of childbearing age and infants, because of the limited supply. When Rh-negative trauma patients (male or female) receive Rh-positive blood components, they are at risk of alloimmunization to the D antigen.\(^\text{51}\) However, if the patient’s ABO and Rh type is known with certainty, but there is no time for crossmatch compatibility testing, then the patient should reasonably receive type-specific products, rather than defaulting to universally compatible products (O-negative RBCs and AB plasma). Most importantly, any un-crossmatched unit that is issued should be clearly labeled as such.\(^\text{1}\) In urgent circumstances, blood components often need to be transfused as quickly as possible, and large-bore intravenous catheters can be used for this purpose.

In addition, when blood losses are substantial, blood infusers can be utilized to rapidly infuse blood components. Rapid infusers can deliver warmed blood components at infusion rates exceeding 500 mL per minute through a pump, which is far faster than the rate that a standard infusion can be programmed to deliver.\(^\text{52}\) Given this rapid rate of infusion, it is essential that blood components are warmed in order to prevent hypothermia-induced coagulopathy.\(^\text{53}\) Rapid infusers are frequently credited with providing lifesaving delivery of blood, although care should be taken to avoid air emboli.\(^\text{54}\) Newer models of infusion pumps are reported to have improved safety features to prevent infusion of air emboli, which can cause a fatal tricuspid valve occlusion.\(^\text{55}\)

**Blood warming and bedside blood pumps**

Stand-alone blood warmers may be utilized when large volumes of blood components are transfused (without a rapid infuser) or when patients have cold agglutinins detected during compatibility testing. Only validated, approved blood warmers should be used for this process in order to ensure patient safety. Such approved blood warmers often consist of tubing coiled around a central heating core that is temperature monitored. Blood must never be warmed by holding the unit in a hot water stream under a faucet or by heating it in a standard microwave oven. Hemolysis is a real danger with either of these methods. Monitored blood warmers are frequently used during lengthy apheresis procedures to promote patient comfort. Importantly, nonwarmed blood has been shown to lower the core temperature of transfusion recipients, possibly contributing to cardiac arrest.\(^\text{56}\) Interestingly, it has been reported that repeated plasma exchanges using a blood warmer may actually result in clinically significant blood loss.\(^\text{57}\) Blood warmers must be maintained regularly to prevent malfunction and possible hemolysis. Blood can also be administered through medication infusion pumps if they have been shown to not cause shear stress–induced hemolysis. These devices are often used for neonatal or pediatric transfusions when precise infusion volumes are needed. Not all pumps are compatible with red cell infusions, so each device needs to be evaluated to ensure red cell compatibility.

**Post transfusion**

At the completion of the transfusion, the patient should be checked again for any signs of an adverse reaction to the blood component, and a final set of vital signs should be taken. Because transfusion reactions can occur several hours after the completion of the transfusion, inpatients should be monitored for at least 4–6 hours after a transfusion is completed. If a patient will be discharged from an ambulatory care setting after receiving a transfusion, then written documentation of signs and symptoms of transfusion reactions and a telephone number of a responsible practitioner should be provided to the patient prior to leaving the clinic.\(^\text{14}\)

**Key references**

A full reference list for this chapter is available at: [http://www.wiley.com/02/52/8go/simon/transfusion](http://www.wiley.com/02/52/8go/simon/transfusion)


