Supplying blood to the battlefront has been an ever-growing challenge since its inception in the First World War, when blood collection and transfusions came of age. During the early phases of Operation Iraqi Freedom, blood supplies were difficult to acquire and maintain because of the dynamic and austere environment of the battlefield. To ensure adequate supplies to meet patients’ needs during emergency situations, some units collected and transfused whole blood.

The FST Concept

The fall of the Berlin Wall brought many changes, including the way the US Army would fight future battles. For many years, the Cold War had provided the US Armed Forces a single enemy, and only a linear concept of fighting a war. Military planners soon realized that the post–Cold War battlefield would be characterized by quick-moving military operations in which mobility, flexibility, and geographically extended lines of communication would be key elements to success.1 In order to support the changing battlefield, the FST concept was developed in 1987, leading to a significant change in how the Army Medical Corps delivers wartime health care. The concept of the FST is based on research from earlier conflicts that indicated that

From Donor to Patient in 20 Minutes
Emergency Resuscitation With Whole Blood During Operation Iraqi Freedom

David Cassella, RN, MSN, CCRN, CCNS
George Appenzeller, MD
John Stich, RN, MSA, MSN, CCRN

PRIME POINTS

- Hemorrhage is the leading preventable cause of morbidity and mortality on the modern battlefield.
- For patients with hemorrhage, whole blood transfusion is a practical option to counter the lack of supply and lack of clotting factors.
- Walking blood banks require no refrigeration and can provide a wide variety of blood types.
- Fresh whole blood can reverse the effects of hypothermia, acidosis, and coagulopathy.

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hemorrhage was the most common cause of preventable mortality.\(^1\) The earlier experiences showed that the faster a casualty was treated and stabilized, the more mortality and long-term morbidity were reduced. Operation Iraqi Freedom is the first large-scale test of the Army’s new concept of placing surgical assets close to the fighting and potentially right in the heat of battle.

An FST consists of a 20-person team that can provide around-the-clock surgical and postoperative care for up to 30 patients in a 72-hour period without resupply\(^2\) (Figure 1). Typical surgical candidates for a FST include patients with major chest or abdominal wounds, uncontrolled or continuous hemorrhage, severe shock, airway compromise, and closed head injuries with progressively deteriorating levels of consciousness.\(^1\) The section breakdown and team organization are described in more detail in the Table.

**Blood Capabilities of an FST**

Mobility is critical to the success of an FST, so limitations must be set on supplies, blood, and equipment. Increasing the weight of an item or the space it requires will directly increase the overall size of the FST and slow the team’s movement. The time frame for FST operations (48-72

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**CASE STUDY**

During the battle, a young soldier with a gunshot wound was transported by helicopter to our FST. The primary survey by the team’s general surgeon revealed a gunshot wound that began in the left lower part of the abdomen and ended at the posterior of the left flank at approximately the eighth thoracic vertebra. No other injuries were noted. Fluid replacement therapy was initiated with lactated Ringer solution, and the patient was moved into the operating room. Immediately after the move to the operating room, the patient’s condition began to worsen; marked hypotension, marked tachycardia, and deterioration in mental status occurred. The patient was quickly anesthetized, and an exploratory laparotomy revealed that bone fragments of the left iliac crest had lacerated the renal artery and vein. Surgery was performed to repair the vessels.

During the surgery, transfusion of packed red blood cells (PRBCs) was started with a rapid infuser. Because of a persisting compromise in hemodynamic status, the patient continued to receive transfusions throughout the operation, for a total of more than 10 units of PRBCs. The initial stabilization surgery was completed, and the patient was transferred to the recovery section for stabilization and further fluid replacement. Despite aggressive fluid replacement, the patient’s hemodynamic status remained

**Authors**

MAJ David Cassella, ANC, USA, is a graduate of the critical care clinical nurse specialist program at the University of Pittsburgh School of Nursing, Pennsylvania. He is currently serving as chief of the Medical-Surgical Specialty Nursing Section, Winn Army Community Hospital, Fort Stewart, Georgia.

LTC(P) George Appenzeller, MC, USA, is deputy commander for clinical services, Winn Army Community Hospital, Fort Stewart, Georgia.

MAJ John Stich, ANC, USA, is a graduate of the critical care clinical nurse specialist program at the University of Pittsburgh School of Nursing. He is currently serving as the commander/chief nurse of the 126th Forward Surgical Team, 1st Medical Brigade, Fort Hood, Texas.

Corresponding author: David Cassella, RN, MN, CCNS, CCNN, 95 Montauk Ln, Richmond Hill, GA 31324 (e-mail: david.cassella@us.army.mil).

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unstable, and coagulopathy developed. The patient was rushed back to the operating room to ensure that no injuries had been missed and that the graft from the previous surgical repair had not failed. During the second surgery, the patient experienced ventricular fibrillation, which the surgeon attributed to continued fluid depletion. Defibrillation was successful, but the patient continued to have pulseless ventricular fibrillation. No surgical evidence was found for the patient’s continued unstable hemodynamic status, and the coagulopathy further complicated the resuscitation because bleeding from the surgical incision, gunshot wound, intravenous catheter sites, nares, and rectum occurred.

Being in an austere environment, the FST carried only PRBCs and had no blood components to treat the coagulopathy. Because of the desperate need for coagulation components to potentially save the patient’s life, the decision was made to use transfusions of whole blood. The call for donors went out, and volunteers began donating almost immediately. Despite vasoactive medication, continued volume replacement, and transfusion of whole blood, the patient continued to experience marked periods of hypotension and bradycardia. The patient ultimately died 12 hours after arrival, after receiving more than 10 units of type-non-specific PRBCs and 8 units of whole blood.

Indications for the use of fresh whole blood (FWB) have been reported. Jevtic et al described using autotransfusion to supplement limited blood supply for treatment of massive hemothorax during high-intensity combat in the territories of the former Yugoslavia during 1991 and 1992. During the war in Croatia in the early 1990s, Horzic et al noted the importance of transfusion services during wartime to ensure that adequate amounts of whole blood are readily available. FWB has been used within the military community during significant time temperatures often exceed 49°C (120°F), ensuring shelf life, and coordinating resupply caused major difficulties for our blood bank in addition to the normal complications associated with maintaining stored blood.

Figure 1 Deployable rapid assembly shelter tents set up on the outskirts of Karbala.
conflicts when subcomponents such as platelets and frozen components were not available. In Somalia, FWB was used after the entire supply of PRBCs was used, and in the first Gulf War, FWB was used when platelet supplies were exhausted.

During combat operations, limitations and restrictions in blood products affect the decision of when to use blood and/or how much blood to use for the situation at hand. Each medical unit must decide how to augment its blood supply in crisis situations when immediate resupply is not an option. Use of FWB is a practical option in these extreme situations, and each soldier deployed is a source of whole blood.

Establishing a Walking Blood Bank

Recognized shortfalls of blood and/or blood components have been a wartime reality, and health care providers have needed to adapt. The principle of walking blood banks is not new; it has been documented in the literature and is an effective alternative to stored blood. Medical units have typed and screened assigned personnel before deployment to further augment the units’ own organic blood supply. The screening process used by the FST for this emergency blood requirement relies on donors’ answers to screening questions and the predeployment processing system. Predeployment processing is a screening evaluation completed on all military personnel before they are deployed to ensure that they are healthy enough to deploy, have received all required vaccinations, are free from communicable diseases, and have proper blood-typing documentation. For example, the screening

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![Figure 2 Portable blood refrigerator typically used by forward surgical teams.](http://ccn.aacnjournals.org/)
prevents deployment of soldiers who have a positive test for infection with human immunodeficiency virus or have other communicable diseases. Hepatitis vaccinations are a requirement for all medical personnel. Prescreening before FWB donation confirmed each donor’s general state of health, verified blood type, and completion of all required immunizations.

Walking blood banks require no refrigeration and can provide a wide variety of blood types. When the need arises for additional blood, this prearranged walking blood bank offers ready access to FWB; prescreened donors require only a rapid recertification before blood is donated. However, this type of walking blood bank has a major drawback for the FST. Donation of blood can affect some donors physically, and these donors would require time to recover, a luxury an FST cannot afford with limited personnel and 24-hour operations.

**Urgent Need for Blood**

Upon receiving word from the primary general surgeon that FWB was needed, we notified personnel in the base camp that a soldier was in urgent need of blood. Within minutes, a line of nearly a dozen soldiers had formed. Our blood donation collection system consisted of a primary container with 63 mL of a solution of the anticoagulant citrate phosphate dextrose and a satellite container with 100 mL of Optisol brand preservative solution for red blood cells (Terumo Medical Corp, Tokyo, Japan). We did not use the satellite container, which is used for collecting plasma and cryoprecipitate. With the primary container, approximately 450 mL of blood can be collected. The collection system includes all the required tubing and needles for collection. Blood was collected from an antecubital vein, while the collection container was gently rocked, until the container was full. During this process, additional samples were collected for further testing of the blood for hepatitis B and C viruses, human immunodeficiency virus, syphilis, and human T-cell lymphotropic viruses I and II; a donor tracking system should be in place to locate donors if indicated.

After collection, the blood was immediately given to the staff caring for the patient for immediate infusion. The blood was run through a rapid fluid infuser by using blood tubing, and each unit of blood was followed by 250 mL of normal saline intravenous solution. The time from questioning of the first donor soldier to bedside delivery of the first unit of FWB was less than 20 minutes.

**Discussion**

In the most severely injured casualties, preventing the lethal triad of hypothermia, acidosis, and coagulopathy is paramount. FWB can be a key component in the reversal of the effects of this triad. Treatment with FWB can reverse dilutional coagulopathy associated with transfusing large amounts of preserved red blood cells.

Whole blood and PRBCs differ markedly. Type O whole blood has benefits in correcting coagulopathy that may offset the inherent risks of giving FWB. FWB is readily available, can increase both red cell mass and plasma volume, and contains clotting factors, which were critical for the patient described in the case study and are not otherwise available. Levels of coagulation factors II, V, VII, IX, X, XII, and XIII and fibrinogen are well preserved in stored whole blood. In total, 1 unit of PRBCs (335 mL) plus 1 unit of platelets (50 mL) plus 1 unit of fresh-frozen plasma (275 mL) provide 660 mL of fluid with a hematocrit of 0.29, 88 000 platelets, and 65% coagulation factor activity. In contrast, 1 unit of FWB (500 mL) has a hematocrit of 0.33 to 0.43, 130 000 to 350 000 platelets, and 86% coagulation factor activity.

Whole blood transfusions are a tried and proven concept. The systemic effects—improved intravascular volume, decreased or limited third spacing, enhanced oxygen carrying capacity, and replenishment of coagulation factors—all prove the effectiveness of this therapy. Replacement solely with crystalloids and PRBCs may aggravate coagulopathy further. Experience in treating the severely wounded in Operation Iraqi Freedom has indicated that patients may already have coagulopathy upon admission to an FST. Anecdotal evidence from health care personnel who treated trauma patients in Iraq suggests that decreased crystalloid use in the first 24 hours results in less postoperative edema and may improve ventilation and decrease duration of mechanical ventilation. During the situation discussed in this article, treatment with FWB provided the only possible solution available at the time to reverse the coagulopathy experienced by the patient.
Summary

Whole blood transfusion should be considered as an option for treatment of patients with unresponsive hypovolemic shock or coagulopathy during war or during shortages of blood components in a domestic disaster. With planning, appropriate supplies, and access to a walking blood bank, whole blood transfusion can be a safe and rapid alternative in times of critical blood shortages. Use of whole blood has played an important role in the history of war and treating wounded soldiers; its use should still be considered relevant, especially for replacing clotting components that are not readily available in a combat theater of operations.

Acknowledgment

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Financial Disclosures

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