Far Forward Anesthesia and Massive Blood Transfusion: Two Cases Revealing the Challenge of Damage Control Resuscitation in an Austere Environment

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Since the beginning of Operation Enduring Freedom and Operation Iraqi Freedom in 2001 and 2003 respectively, the US military has treated more than 51,000 casualties and sustained more than 6,600 deaths. The past decade of conflict has solidified major advances in the use of blood component therapy and the liberal use of fresh whole blood during damage control resuscitation. This resuscitation strategy, combined with far forward damage control surgery, rapid aeromedical evacuation, and major improvements in critical care air transportation and personal protective equipment has led to a 90% to 92% survival rate in US casualties.2,3 We describe 2 cases treated by a Forward Surgical Team serving in Afghanistan during Operation Enduring Freedom in 2014. Both patients suffered severe trauma and required massive blood transfusion and damage control surgery. In describing these 2 cases, we wish to share our experience with damage control resuscitation in an austere environment, as well as advocate for the critical role of the Certified Registered Nurse Anesthetist in advancing the knowledge and execution of this lifesaving strategy in both military and civilian trauma centers. In addition, we suggest alternatives to the current transfusion strategy, which will mitigate limitations currently encountered.

Keywords: Damage control resuscitation, Forward Surgical Team, fresh whole blood.
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The FST is a 20-member team positioned in the forward combat zone. An FST consists of a command element, a trauma resuscitation (advanced trauma life support) section, the operating room (staffed with 3 general surgeons, 1 orthopedic surgeon, 2 CRNAs, 1 registered nurse, and 3 operating room [OR] surgical technicians), and an intensive care unit. The FST mission is to initiate resuscitation, provide immediate lifesaving surgical interventions, stabilize extremities; and support critical care transport to a higher level of care.7 Since World War I, the CRNA is predominately the only anesthesiology provider deployed in a Forward Operating Base in areas of combat.8 Tasked with the responsibility for the entire anesthetic process, CRNAs must critically analyze information and rapidly develop a plan of care, often with little or no medical history, and safely deliver lifesaving anesthetic care to our nation’s warfighters, and must do so with limited resources in the most austere of environments.9 An FST is resourced to provide continuous casualty care and perform up to 30 operations in 72 hours.7 The FST has no laboratory or x-ray capability but is often co-located with a brigade support battalion, which provides this capability. Forward Surgical Teams are strategically positioned in the combat theater to ensure that all combat casualties arrive from the point-of-injury within the “golden hour,” offering the highest probability of survival. The austere environment, limited resources and personnel, and severity of injuries sustained highlight the ongoing challenges the CRNA and surgical team have to providing care to our injured warfighters.

Currently in Afghanistan, all blood components except whole blood and platelets are delivered from the United States on a weekly basis. All products are inventoried, then distributed to the FSTs in theater on a weekly basis or as operational supply dictates. An FST carries only PRBCs, fresh frozen plasma (FFP), and cryoprecipitate. No platelets are available in the forward combat zone. We estimated that our FST gets components that are between 14 and 28 days old, with a mandated expiration of 42 days. The current blood bank inventory of our FST is roughly 90 U of PRBCs, 25 U of FFP, and 55 U of cryoprecipitate.

Case Summary

Case 1. National elections in the Islamic Republic of Afghanistan occurred on April 5, 2014. A 38-year-old male civilian was leaving the local voting station in Logar province when he was fired on by insurgents. International Security Assistance Forces provided immediate tactical combat casualty care and transported the patient to the 932nd FST. He arrived via ground evacuation. Primary survey revealed multiple gunshot wounds to the left side of the chest, left side of the back, and flank.

Table. Pertinent Laboratory Values

<table>
<thead>
<tr>
<th>Patient 1</th>
<th>Patient 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Zero</td>
<td>120 min</td>
</tr>
<tr>
<td>pH</td>
<td>6.5</td>
</tr>
<tr>
<td>Pco₂, mm Hg</td>
<td>75.5</td>
</tr>
<tr>
<td>Po₂, mm Hg</td>
<td>23</td>
</tr>
<tr>
<td>Hco₃, mm Hg</td>
<td>15</td>
</tr>
<tr>
<td>Base excess, mEq/L</td>
<td>–18</td>
</tr>
<tr>
<td>Hemoglobin, g/dL</td>
<td>6.8</td>
</tr>
<tr>
<td>Hematocrit, %</td>
<td>20</td>
</tr>
<tr>
<td>Temperature, °C (°F)</td>
<td>36.3</td>
</tr>
<tr>
<td>(97.2)</td>
<td>(93.5)</td>
</tr>
</tbody>
</table>

His vital signs on arrival were as follows: blood pressure (BP), 70/40 mm Hg; heart rate (HR), 114/min; respiratory rate, 45/min; arterial oxygen saturation (SaO₂), 71%; and body temperature, 36.3°C (97.2°F). He was awake and alert and in obvious distress. Initial arterial blood gas analysis demonstrated the following values: a pH of 6.9, Pco₂ of 75.5 mm Hg, Po₂ of 23 mm Hg, Hco₃ of 15.0 mm Hg, and a base deficit of –18. The Table summarizes pertinent laboratory values, and Figure 1 shows the total number of blood products given during each case.

Rapid-sequence intubation was performed and a left-sided chest tube placed, with a return of 100 mL of blood. The patient went into cardiac arrest, and an advanced cardiac life support/advanced trauma life support protocol was initiated. A 7F introducer was placed in the right femoral vein, and the first unit of PRBCs began infusing via a Belmont Rapid Infuser (Belmont Instrument Corp; capable of delivering 750 mL/min infusion rate). A right-sided chest tube was placed without return of fluid. Emergent left-sided anterolateral thoracotomy was performed, revealing no evidence of pericardial tamponade or left-sided chest hemorrhage. An aortic cross-clamp was placed, with return of a carotid pulse. Results of the physical examination confirmed a distended abdomen, and he was taken immediately to the operating room for exploratory laparotomy.

Initial laboratory test results in the OR demonstrated a hemoglobin level of 6.8 g/dL, hematocrit concentration of 20.0%, platelet level of 114 × 10⁹/µL (114,000), prothrombin time of 28.3 seconds, and international normalized ratio (INR) of 2.5, showing the early coagulation of trauma. An additional introducer was placed in the right internal jugular vein to ensure access above and below the diaphragm. Laparotomy findings revealed gross blood and contamination. At this point, 4 U of PRBCs were infused, an MT protocol was initiated, and...
FWB donors were activated. A 1-g bolus of tranexamic acid was given, and a 1-g infusion was begun; 2 ampules of sodium bicarbonate were given. During the next 30 minutes, 16 U of PRBCs and 2 U of FFP were infused. Exploratory laparotomy revealed injuries of the stomach, tail of the pancreas, spleen, and left kidney. Rapid gastrotorrhaphy, pancreas stapling, splenectomy, and left nephrectomy were performed. On entering the lesser sac, substantial bleeding around the aorta was noted and full visceral mobilization revealed substantial bleeding from around the spine. Attempts to identify discrete bleeding vessels were unsuccessful, and ultimately packing with hemostatic agents was attempted. The patient demonstrated a labile systolic BP from 60 to 85 mm Hg with a pH of 6.78 and $P_{CO_2}$ of 44 mm Hg. An FWB transfusion was initiated 70 minutes after the start of the procedure. A diffuse coagulopathy was clinically evident, with extensive bleeding from every peripheral intravenous (IV) puncture site, the thoracotomy site, and the patient’s eyes and nose. Four-quadrant abdominal packing and temporary closure were performed, and the thoracotomy incision was closed.

The patient was unresponsive to norepinephrine bitartrate (Levophed), epinephrine, and massive resuscitation, and he was declared dead 2 hours after arrival to the FST. He had received 26 U of PRBCs, 5 U of FFP, 3 U of FWB, and 1 U of cryoprecipitate.

**Lessons Learned.** Following the care of all patients in the FST, an “After Action Review” is conducted to provide constructive criticism on team performance with a focus on specific items for improvement or remedial instruction. One major critique was our failure to adhere to the transfusion of PRBCs and FFP in a 1:1 ratio because of a lack of prepared thawed products at our request and the inability to keep up with the volume of required products as outlined in the damage control resuscitation guidelines. Packed red blood cells are maintained at $4^\circ$C and are immediately available in large quantities. Fresh frozen plasma is stored at $-20^\circ$C, and thawing requires approximately 30 minutes in a warmer. Because of the thin plastic bags in which FFP is stored, approximately 25% will experience a break in the bag as thawing occurs, rendering them unavailable for use. If this is discovered early in the thaw cycle, that unit can be replaced immediately; however, if this is discovered at the conclusion of the 30-minute cycle, preparation of the next unit is greatly delayed. During administration through a Belmont infuser, 2 U of FFP and 2 U of PRBCs can be infused in under 2 minutes. Therefore, the rate of infusion can easily outpace the supply of blood products, creating a major delay in ongoing resuscitation.

Another factor noted during the After Action Review was the inefficient execution of the whole blood drive. Prescreened donors were slow to be notified and had delays in arriving at the aid station because of a recent change in location on the base. Once initial triage was completed, BP cuffs were used as tourniquets to place IV catheters and draw blood. These cuffs were inflated much higher than recommended, occluding arterial pressure and resulting in poor blood flow. Because of the time constraints in donation (clot formation limits blood draws to 15 minutes), the bags of FWB obtained contained 100 to 200 mL of blood, much less than the 400 to 500 mL typically obtained from a healthy donor under different circumstances.

Through problem recognition and constructive feed-
back, several steps were taken to reeducate personnel and optimize resources. We implemented protocols to keep 4 U of FFP thawed and ready for immediate use at all times. Additional FFP would be thawed as soon as this FFP was requested. Laboratory technicians were instructed to examine thawing FFP every 5 minutes to maximize identification of broken units and quickly facilitate thawing of additional units. All medics involved in drawing blood from donors were trained in an in-service on correct tourniquet technique. Additional donors were identified and prescreened, and a phone roster and basewide overhead system were implemented to aid in rapid notification of these critical human resources.

- **Case 2.** A 23-year-old male Afghan police officer with a gunshot wound to the left lower aspect of the abdomen and multiple gunshot wounds to bilateral lower extremities was brought to the FST via ground transportation. Primary survey revealed extremity tourniquets in place on both upper thighs with no palpable distal pulses, open fractures of the left femur and tibia, and evisceration of the small bowel from the lower left-sided abdominal wound. Initial vital signs demonstrated a BP of 70/39 mm Hg, HR of 44/min, respiratory rate of 30/min, oxygen saturation of 92%, and body temperature of 36.6°C (97.9°F).

Rapid-sequence intubation was performed, and initial laboratory test results demonstrated a pH of 6.5 and Pco₂ of 54.5 mm Hg. (Not all laboratory values were returned with the initial specimen.) The patient was taken to the OR for exploratory laparotomy. A subclavian introducer and large-bore peripheral IV catheter were placed, 4 U of PRBCs and FFP each began infusing via the Belmont infuser, and a 1-g bolus of tranexamic acid was given. Exploratory laparotomy identified multiple small-bowel injuries with gross contamination. With use of damage control surgical principles, 2 segmental small-bowel resections were performed, leaving both ends in discontinuity. At this point, it was noted that the patient was exsanguinating from his lower extremity wounds, likely the result of improved perfusion. Temporary abdominal closure, repositioning and tightening of tourniquets, and x-ray imaging of the lower extremity were simultaneously performed.

Local wound exploration revealed injury to the right popliteal artery. Up to this point, approximately 10 U of PRBCs, 8 U FFP, and 2 U of cryoprecipitate had been given. Recognizing the severity of the popliteal artery injury and the need for surgical repair or shunting, the surgical team initiated the FWB protocol. While surgical exploration and control of the popliteal artery and vein were performed, we continued to transfuse PRBCs and FFP in 1:1 ratio with additional cryoprecipitate until we obtained FWB, which arrived 27 minutes following initiation of the FWB drive. During the next 2 hours, the surgical team performed a right popliteal artery shunt and vein ligation, 4-compartment fasciotomy of the right lower extremity, external fixation of the left tibia-fibula fracture, left popliteal artery exploration with angiogram, and 4-compartment fasciotomy of the left lower extremity. Throughout this timeframe, FWB was given as a resuscitation fluid, normothermia was maintained, and minimal crystalloid was infused following DCR protocols.

The patient received a total of 18 U of PRBCs, 18 U of FFP, 2U of cryoprecipitate, and 24 U of FWB. At the conclusion of the case, the patient had a pH of 7.5, hemoglobin level of 7.1 g/dL, and INR of 1.8, with a BP of 100/48 mm Hg, HR of 142/min, SaO₂ of 100%, and body temperature of 38.4°C (101.2°F). He was subsequently transferred to the Craig Joint Theater Hospital at Bagram Air Field for further definitive care.

**Discussion**

These 2 cases are examples of severely injured combat casualties who received MT, with a dramatic difference in outcome. Patient 1 experienced trauma-induced coagulopathy secondary to the surgical team’s inability to maintain a high ratio of PRBCs to plasma and to infuse an adequate quantity of FWB. The inability to transfuse necessary platelets, clotting factors, or FWB in a timely manner allowed him to progress to the lethal triad of coagulopathy, acidosis, and hypothermia. Patient 2 had a similar injury severity, but the early and aggressive use of FWB and plasma provided the necessary endogenous clotting factors and platelets to promote hemostasis in the setting of MT. These cases highlight the unique characteristics of combat casualty care and the daunting challenge the CRNA has in executing DCR for the severely injured. Our results suggest that efforts to incorporate this resuscitation strategy into civilian practice may improve outcomes, and warrant continued study.

Damage control resuscitation is the US military’s current guideline for arresting hemorrhage, minimizing crystalloid infusion, replacing appropriate blood products, preventing dilutional coagulopathy, providing oxygen-carrying capacity (PRBCs), and restoring sufficient circulating volume to improve tissue perfusion and correct metabolic acidosis while decreasing the risk of rebleeding. It is not just the transfusion of blood components, but an overall approach to treat severe hemorrhage and the combined deleterious effects of the coagulopathy of trauma on physiology. Damage control resuscitation was proposed in 2004 as an alternative approach to resuscitation of combat casualties in hemorrhagic shock. The strategy involves the following:

1. Prompt identification of casualties at risk of needing an MT
2. Rapid control of surgical bleeding
3. Early use of red blood cells, plasma, and platelets in a 1:1:1 ratio
4. Limited crystalloid infusion
5. Prevention and treatment of hypothermia, hypocalcemia, and acidosis
6. Hypotensive resuscitation strategies

Findings of large retrospective cohort studies of combat casualties demonstrate a significant survival benefit when RBCs, FFP, and platelets are transfused in a 1:1:1 ratio. Damage control resuscitation also advocates the transfusion of FWB for casualties who are anticipated to require MT, for those with clinically significant shock or coagulopathy when optimal component therapy is unavailable, or when the patient is not responding adequately to blood component therapy. These massively transfused casualties have a historically high mortality rate (33%) and have the greatest potential to benefit from aggressive transfusion strategies. Fresh whole blood offers a number of advantages to blood component therapy alone. Although the definition of 1 U of any blood component is the amount of that component found in 1 U of whole blood, in reality, that is not the case. For example, by definition 1 U of FWB provides 100% coagulation factor activity, whereas coagulation factor functional activity in 1 U of FFP is approximately 65% of that found in whole blood, resulting in a less effective hemostatic resuscitation. Figure 2 provides a detailed comparison of whole blood activity compared with individual components. Further limitations of current blood component therapy include degraded plasma proteins in FFP, the red blood cell storage lesion seen in PRBCs, and inherent dilution of clotting factors due to addition of anticoagulants and preservatives. Clearly, blood component therapy, no matter how close to a 1:1:1 ratio, does not equal what is found in whole blood; thus, the total is not equal to the sum of its parts.

Despite its many benefits, FWB is not without risks. Potential risks include transfusion reactions, increased infectious risks, graft-versus-host disease, decreased exercise tolerance in donors, and the possibility of clerical errors. In civilian centers, the risk of bacterial and/or viral contamination of blood is always listed as a potential transfusion-related morbidity. However, recent analysis of approximately 10,000 FWB transfusions in US personnel confirm the safety of this product, with only 1 case of hepatitis C virus transmission, 1 human T-lymphocyte conversion, and 1 fatal case of transfusion-associated graft-versus-host disease.

During Operation Enduring Freedom and Operation Iraqi Freedom, FWB is readily available thanks to the “walking blood bank.” In essence, once MT and whole blood requirements are recognized, a whole blood drive is initiated through a common communication system. Several hundred prescreened and pretyped donors rapidly proceed to an aid station, where vital signs are measured, large-bore IV catheters are placed, and blood is drawn into a 500-mL bag, with minimal dilution by additives. Rapid testing for HIV, hepatitis B, and hepatitis C is performed, with an approximate 85% sensitivity. In comparison, the American Red Cross estimates the incidence of hepatitis transmission in the United States to be 1:200,000 and HIV to be 1:2,000,000. The FWB is then rapidly infused, frequently while still warm. By regulation, blood collection from the donor must be completed within 15 minutes to minimize risk of clots forming in the collection tubing. The use of FWB is a unique and vital resource in the combat theater. The composition of 1 U of FWB is superior to blood component therapy, providing a hematocrit concentration of 40%, a platelet count of 150,000, 100% coagulation factor activity.
activity, and 1,500 mg of fibrinogen. In contrast, the combination of 1 U of PRBCs, 1 U of FFP, 1 U of platelets by apheresis, and 10 U of cryoprecipitate effectively delivers a hematocrit concentration of 29%, a platelet count of 87 ×10^3/μL (87,000), 65% coagulation factor activity, and 750 mg of fibrinogen.

A retrospective analysis comparing combat casualties who received FWB and blood component therapy compared with those who only received component therapy revealed increased survival in FWB recipients. Although blood component therapy has evolved in the civilian community as the standard of care, based on the military experience, the use of FWB should be reconsidered for civilian casualties who require an MT. Ironically, FWB is not approved by the US Food and Drug Administration because of the absence of rigorous pathogen testing and is not indicated for routine use, although the outlined benefits certainly warrant reevaluation of this limitation.

Substantial hemorrhage at point of injury and the traditional paradigm of crystalloid fluid resuscitation initiates a lethal triad of acidosis, coagulopathy, and hypothermia. Packed red blood cells lack plasma with all its inherent supplemental clotting factors, and the rapid administration of PRBCs in the severely injured patient can lead to a dilutional coagulopathy. In patient 1 we were unable to meet the 1:1 ratio of PRBCs to FFP or obtain FWB in a timely manner that would have allowed us to treat the lethal triad and prevent a “horrible coagulopathic death.” Following this fatal case and recognition of a number of correctable conditions, we reeducated personnel and retasked our resources. During the second whole blood drive, major improvements were demonstrated, as evidenced by the survival of the patient, the almost perfect transfusion ratio of 1:1, and the timely use of FWB preventing lethal coagulopathy.

These 2 cases highlight the challenge of delivering blood component therapy as well as FWB to the critically injured patient under current tactical conditions. These resuscitations require an enormous effort by the CRNA tasked with assessing and implementing the DCR protocol as well as support sections and would not be possible without the walking blood bank. However, as the current conflict in Afghanistan concludes, we suspect that our forward operating bases in theater will be less and less equipped and staffed to efficiently execute these large-scale resuscitations, and reliance on this approach may prove problematic in the near future.

As has always been the case, our military experience has strongly influenced transfusion practices in civilian US trauma centers. Several civilian studies have shown that transfusion of high ratios of FFP to red blood cells (1:1) is associated with improved 24-hour and 30-day survival rates with adherence to an MT protocol. Yet, this approach is not universally accepted. Despite impressive data in the literature, the American Society of Anesthesiologists states in its MT protocol guidelines “an enthusiastic call by some of our trauma surgical colleagues to resort to 1:1:1 ratio of major components may be appropriate for some patients, but may put others at risk of worse outcome and possible higher delayed mortality. More convincing data to replace this exuberant enthusiasm is clearly needed.” Obviously, the lack of consensus warrants further research and validation.

More than 160,000 civilian trauma deaths occur annually in the United States, far exceeding that of the military. Of those patients with severe traumatic injury, 28% will arrive at the emergency department with a coagulopathy. These coagulopathic patients have a 3.5x to 5x higher mortality rate than do noncoagulopathic patients. Lessons learned from combat casualties over the past 13 years have been incorporated into many civilian trauma centers, but are not nearly as widespread as they should be. Only 50% of those Level 1 trauma centers with an MT protocol utilize a 1:1 transfusion ratio of PRBCs to FFP. Adherence to a DCR protocol can help every civilian trauma center or rural hospital increase the survival rates of their severely injured patients by preventing or diminishing coagulopathy and its devastating effects.

In the future, more research regarding trauma, coagulopathy, and hemorrhage is needed. Advancements in the development and widespread implementation of blood products such as freeze-dried plasma, prothrombin complex concentrates, and fibrinogen concentrates are anticipated, but they require more study and research. Coagulation factor concentrates offer potential advantages over allogeneic blood products, such as decreased immunogenic and infectious complications, rapid availability, and long shelf lives. The use of factor concentrates and lyophilized plasma also may lessen the burden of smaller rural hospitals regarding having standby thawed plasma for anticipated traumas, thus increasing their cost savings and improving patient survivability. Obviously, more studies are needed regarding the efficacy and cost-benefit ratio of these alternatives. Multiple studies have shown increased patient survivability with an MT protocol using a 1:1:1 ratio. Although the 1:1:1 ratio is effective, it can prove difficult to execute because of lack of available resources. The benefits that concentrates provide to anesthesia providers cannot be overstated when achieving a 1:1:1 ratio of components is not possible, as exemplified in patient 1. Much research is under way, but freeze-dried products and concentrates should be recognized as possible valuable options in the austere conditions of combat and in the civilian hospital. This area of research should be of paramount importance to the civilian trauma community.

REFERENCES


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