Chapter I
ACUTE RESUSCITATION AND CRITICAL CARE

I.1 Forward Resuscitative Surgery: An Introduction to Polytrauma

CASE PRESENTATION

Two soldiers were standing guard when they sustained multiple gunshot wounds by unknown assailants. Both individuals were treated in the field by a medic and transported to a Forward Surgical Team (FST) facility in nonmedical vehicles. The two soldiers were brought in by their units. Emotions ran high. Their unit had been notified, and several members met these soldiers on arrival at the FST. The first soldier suffered a single, high-velocity wound to the head. On quick inspection, he had agonal breathing and had not been intubated. He was intubated, and the dressing that had been placed around his head was removed. Half of his left cranium was missing, with protrusion of macerated brain matter (an obviously mortal injury). The second soldier sustained multiple wounds, including a partial traumatic amputation of his left hand. High-velocity wounds (see sidebar on page 23) were present with entries and exits to both thighs and scrotum. Rapid assessment of this second soldier revealed that he was awake, alert, and answering questions appropriately. He maintained his own airway and moved air freely. He had no apparent chest or abdominal wounds. Tourniquets were placed just above his left hand and high on the upper portions of both thighs. Intravenous (IV) access was rapidly established, with large-bore IVs in both upper extremities. Initial vital signs revealed mild tachycardia and a systolic blood pressure of around 100 mm Hg. This soldier did have some oozing through dressings that had been placed over his bilateral thigh wounds. Fluid resuscitation was initiated while a secondary survey was completed. No additional upper body injuries were identified. His pelvis appeared stable. His right upper extremity was without injury; he had a partial traumatic amputation just above his left wrist. Lower extremities examination revealed entrance and exit wounds to both upper thigh areas, with apparent bilateral femur fractures. He also had an open scrotum with exposed testicles. His phallus appeared intact. In his lower extremities, the patient had no sign of injury below the thighs. However, he had poor perfusion of both lower extremities. Chest X-ray (CXR) revealed no pneumothoraces. The FAST (Focused Abdominal Sonography for Trauma) exam was negative for free fluid in the abdomen. The pelvis film revealed no pelvic fractures or foreign bodies. Although the patient remained hemodynamically stable, he became progressively combative. The surgeons judged that the patient was on the verge of hemodynamic collapse. Consequently, while receiving fluid and blood resuscitation,

TO OPERATE OR TO TRANSPORT?

This soldier was severely wounded when a vehicle-borne improvised explosive device (IED) exploded near a vehicle where he was standing. The left lower extremity was nearly amputated by the explosion. The right lower extremity was severely injured with multiple fragments, fractures, and a popliteal artery injury. The soldier was treated with a tourniquet above the knee, splinted, and immediately transported to a nearby FST, arriving within 10 minutes of the injury. At the FST, the wounds were assessed. Significant blood loss and hypotension required immediate transfusion of PRBCs and saline. The patient was stabilized. A 45-minute helicopter transport to a CSH was immediately available. The senior surgeon elected to operate on the patient at the FST. Vascular repair was attempted, and an extensive external fixator was placed. The operation lasted approximately 4 hours, and the blood available to the FST was exhausted during the procedure. The patient was then transported via MEDEVAC helicopter to the CSH. En route (approximately 20 minutes into the flight), the patient had a cardiac arrest. Despite attempts at resuscitation, he died.

TEACHING POINTS

1. It is likely that this patient succumbed from the lethal triad of hypothermia, acidosis, and coagulopathy.
2. The surgical mission of an FST is extremely difficult, and difficult to delimit. Although the capability and equipment necessary to perform a wide variety of resuscitative and definitive surgical procedures are available at the FST, the fundamental principle of military surgery makes it imperative that patients who can tolerate transport to the next level of care are stabilized and moved expeditiously to more robust surgical facilities.
3. The judgment of the senior surgeon can be severely tested. Patients should only undergo extensive surgical procedures at the FST if, in the judgment of the senior surgeon, the patient will not survive transport to the next level of care. Even when such dire circumstances prevail, the goal is stabilization such that the patient can tolerate transport to the next level of care.

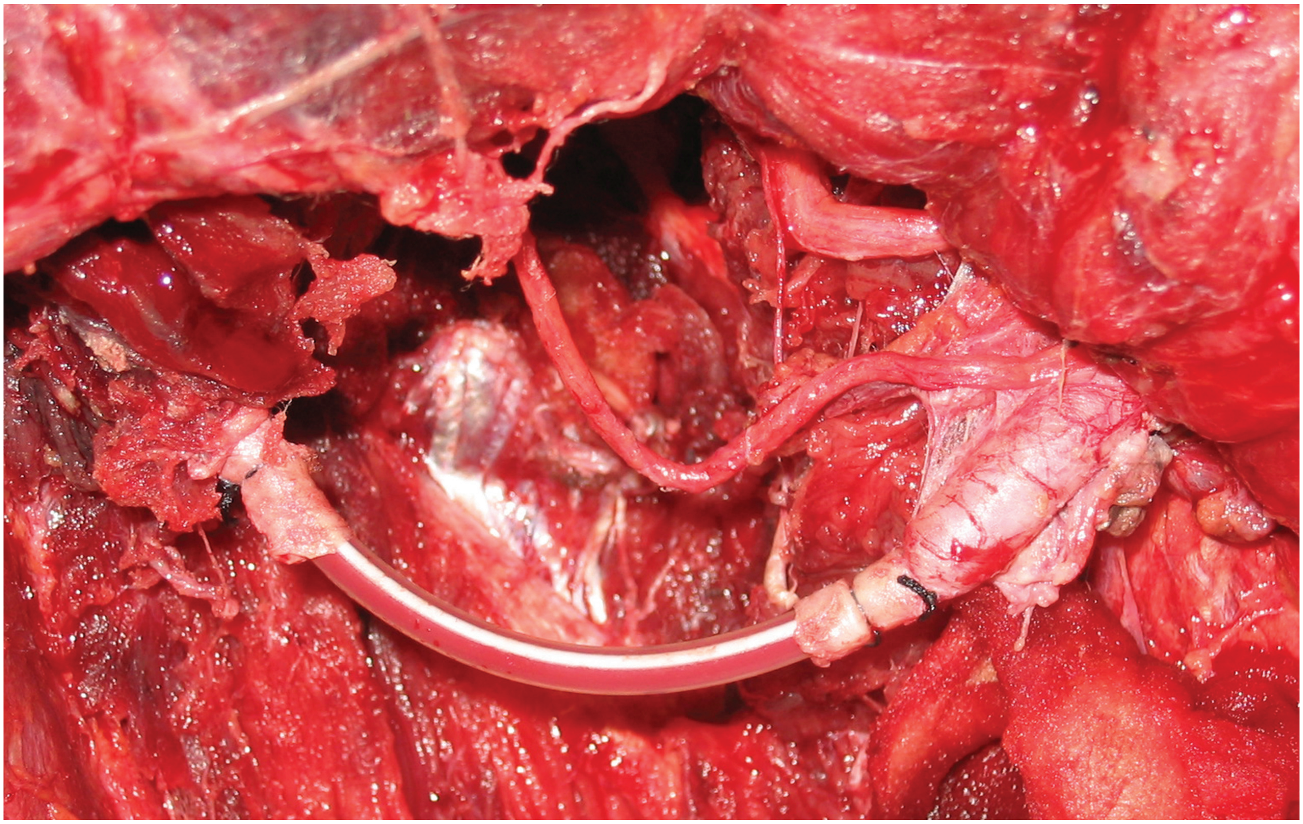


Figure 1. *Extensive loss of tissue associated with a high-velocity wound. A shunt is in place in the SFA.*

he was taken urgently to the operating room (OR) for further evaluation and exploration of his multiple extremity wounds. The "walking blood bank" was mobilized because of the anticipated need for whole blood. In the OR, a pneumatic tourniquet was placed above the dressing and completion amputation of the left hand was rapidly performed. The pneumatic tourniquet was released with no evidence of ongoing bleeding from the extremity. The left thigh had diffuse oozing below the field tourniquet, and a pneumatic tourniquet could not be placed proximally. Therefore, the wound was explored with the field tourniquet in place. The tourniquet was gradually released, and the major sources of bleeding were identified. The superficial femoral vein (SFV) had been transected, and was ligated both distally and proximally. The superficial femoral artery (SFA) was initially in spasm, but began to bleed profusely once the tourniquet was released. The transected ends were identified, and an Argyle shunt was rapidly placed (Fig. 1). Doppler signals were obtained in the dorsalis pedis and posterior tibial arteries. Attention was then directed to the right lower extremity. The SFA appeared intact, but the SFV was transected. The vessel was ligated and bleeding controlled. Exploration of both lower extremity wounds took approximately 1 hour to complete, during which time the patient received 6 units of packed red blood cells (PRBCs) and 4 units of whole blood. Preparation for transport was initiated. External fixators were placed on both lower extremities and fasciotomies performed (Fig. 2). The vascular shunt was reassessed to ensure it had not become dislodged during the previously described procedures. While awaiting transport, the patient's testicles were protected by placing them inside the injured scrotum and loosely approximating the scrotal edges. A repeat FAST exam was performed, which was negative. Because of the severity of the patient's injuries and the need for ongoing resuscitation, one of the FST surgeons accompanied the patient in-flight to the combat support hospital (CSH). The second surgeon called the receiving surgeon and relayed information about the nature of the injuries, status of the patient, and operative procedures performed. Treated expectantly, the first casualty succumbed to his wounds.

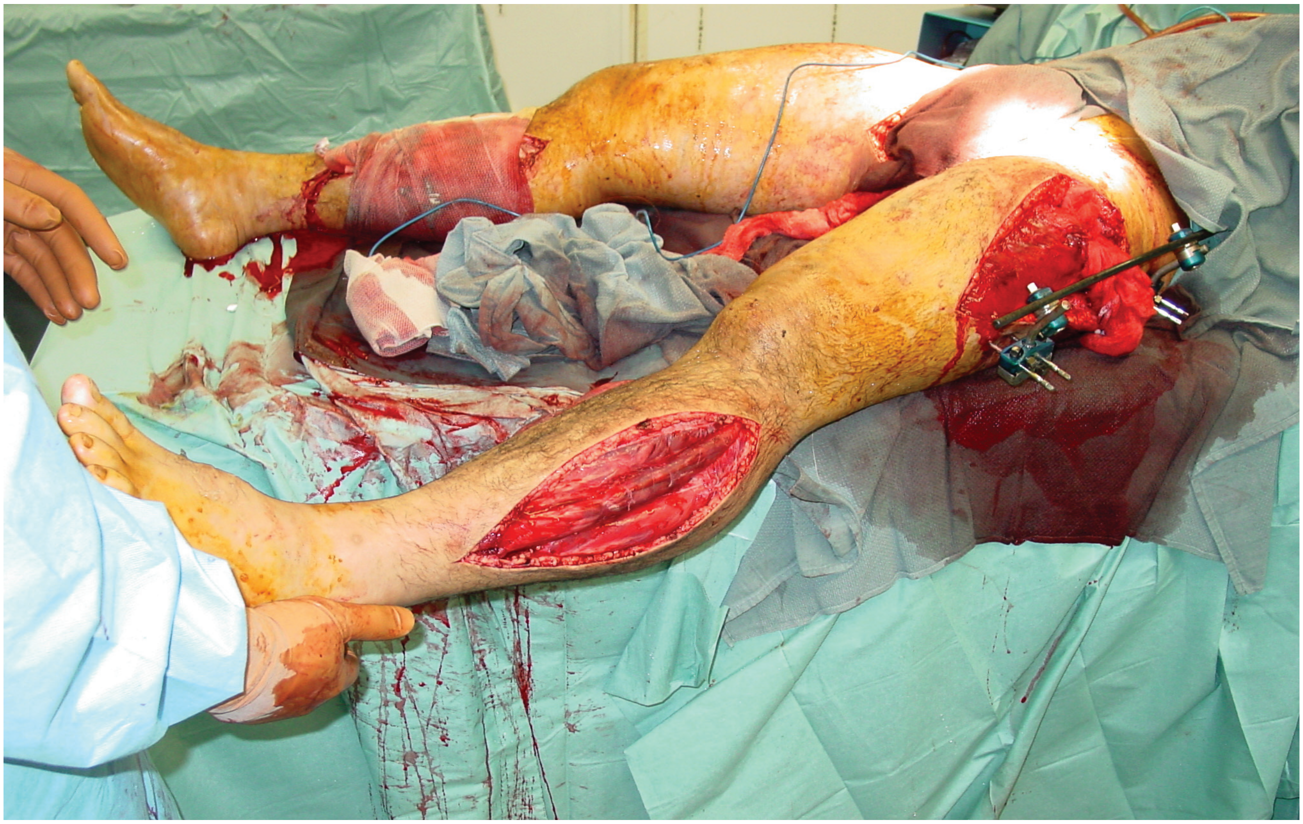


Figure 2. *Compartment release of lateral leg has been performed. External fixation of the left femur is in place.*

TEACHING POINTS

1. This introductory case provides insight into the dynamics of the rapid, reasoned, sequential approach required in the acute management of complex battlefield trauma. Faced with a crowded emergency area and the emotional chaos of the moment, the surgeon nonetheless walks us through a process of: rapid initial assessment, triage, reassessment with attention to the ABCs, exposure, IV placement, early call for a walking blood bank, secondary survey, plain films of the chest and lower extremities, the FAST exam, the move to the OR, distal upper extremity amputation, attention to the lower extremities, control of venous and arterial bleeding to include placement of an arterial shunt, confirmation of distal flow, transfusion, external fixator placement, prophylactic lower extremity fasciotomies, reassessment and repeat FAST exams, transport, and communication.
2. Specifically: Clear the emergency area of all nonmedical personnel, including commanders. Do not allow nonmedical personnel—including those who are injured, their buddies, or their commanders—to become involved with medical triage.
3. The FST has its own blood stock, but it consists of only PRBCs. Neither the FST nor CSH normally has access to fresh frozen plasma or platelets. Whenever it is determined that someone may become coagulopathic, whole blood is drawn.
4. The FST is not traditionally equipped with X-ray capability. In FSTs without X-rays, external fixators are placed based on known landmarks. This procedure requires skill and experience. General surgeons should be capable of performing this procedure.
5. In a combat situation, all possible avenues of communicating pertinent and essential information must be attempted when transporting patients to the next level of care. This may include writing on the patient and/or the bandages (see Fig. 5, page 175), informing accompanying transport and personnel, radiocommunication, e-mail, written records, or even accompanying the patient when exceptional circumstances permit.
6. Combativeness may be an impending sign of hypovolemic shock and hemodynamic decompensation. It is often misinterpreted as sequelae of a closed-head injury, which seldom, if ever, is the case.

7. General surgeons have responsibility for the overall management of polytrauma patients at the FST. Airway management and resuscitation are critical priorities in conjunction with control of hemorrhage.
8. Once bleeding is controlled, external fixation of fractures may be appropriate. Fracture alignment stabilized with external fixators may improve distal perfusion. Definitive vascular repair may be delayed by placing a temporary vascular shunt. If transport times to the next level of care are short (1 hour or less) and the patient can be stabilized, temporizing with the use of tourniquets and splints and rapid transport to the next level of care should be strongly considered (see sidebar on page 20).

CLINICAL IMPLICATIONS

Often, combat wounds will present to the surgeon in a highly chaotic and emotionally charged environment. As demonstrated in this case, adherence to sound principles of military surgery—including triage, resuscitation, damage control surgery, and evacuation with concise communication to the next level of care—is critical to achieving a successful outcome.

DAMAGE CONTROL

This case is representative of the type of damage control surgery performed by an FST. In this case, after appropriate triage, resuscitation was started, hemorrhage was controlled, and evacuation accomplished. Placement of external fixators and lower extremity fasciotomies fall well within the scope of the FST. Definitive vascular repair was performed later at the CSH.

SUMMARY

This case demonstrates well how quickly a small surgical team can become engaged in a life-and-death struggle to save wounded soldiers. In this case, the FST was successful because they understood the signs of impending cardiovascular collapse, studied previous lessons learned from austere environments, and implemented protocols unique to war trauma. This case captures the confusion and chaos small teams must overcome in combat.

SUGGESTED READING

Chapter 3: Triage. In: *Emergency War Surgery, Third United States Revision.* Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 12: Damage control surgery. In: *Emergency War Surgery, Third United States Revision.* Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

DR JANICE MENDELSON AND THE BALLISTICS OF WOUNDING

In this book and elsewhere, trauma surgeons frequently use the phrase "high-velocity wound." Indeed, modern munitions attain extraordinary velocities. But to better understand the mechanics of wounding, the reader should think in terms of "high-energy transfer." It is not the velocity, but the kinetic energy of the projectile, transferred to the tissue, that produces tissue disruption. High-velocity rifle bullets that traverse tissue undeformed and in a stable trajectory may transfer only a small fraction (< 20%) of their kinetic energy, whereas bullets that break up while traversing tissue (and blast fragments) transfer considerably more of their kinetic energy (> 40%), thus resulting in a larger wound. Energy transfer usually is not uniformly distributed along the wound tract. This is because the projectile may yaw, ricochet, fragment, and/or deform in transit. In addition, the casualty presents nonhomogeneous tissue (garments, skin, fat, muscle, organs of varying densities, and bone) with different viscoelastic properties. It is quite possible to produce a massive wound with a (relatively) slow heavy missile that has an unstable trajectory.

This understanding of energy transfer rather than velocity per se as the determinant of the extent of wounds was largely described by scientists at the US Army's Ballistics Research Laboratory at Edgewood Arsenal in Aberdeen, Maryland. One of the investigators responsible for this work was Colonel Janice A. Mendelson. She served as Chief of the Trauma Investigation Branch (Biophysics Division) at Edgewood from 1958 to 1966. Dr Mendelson was one of the first female surgeons in the Army Medical Corps. She was lead investigator for a number of studies concerning the clinical course of military injuries—studies to which our greater understanding today can be attributed. During the Vietnam War, she deployed as a staff surgeon (1970–1971) and worked in a Vietnamese burn unit where she demonstrated the remarkable efficacy of topical mafenide hydrochloride (Sulfamylon).

I.2 Emergency Surgical Airway Management

CASE PRESENTATION

This host nation male was injured by an improvised explosive device (IED) and brought to the combat support hospital (CSH). He sustained extensive facial injuries (Figs. 1 and 2), including a maxillary fracture, a comminuted mandibular fracture, and tongue and soft-tissue injuries. There were also fragment wounds in his abdomen and flank. The patient could only breathe sitting up and was able to maintain his oxygen saturation above 90%. He resisted efforts to place him in the supine position. Consequently, the anesthesiologist could not orally intubate the patient. The decision was made to perform a cricothyroidotomy. While in a sitting position, the patient's neck was prepared with betadine solution. He was given propofol, placed in the supine position, and an immediate cricothyroidotomy performed. The procedure took less than 1 minute. During this time, the patient's oxygen saturation dropped to 45%, but quickly returned to normal once his trachea was intubated (Figs. 3 and 4). With the airway secure, the patient underwent exploratory laparotomy that revealed no intraabdominal injuries. A gastrostomy tube was placed, and facial reconstruction was performed. Within 48 hours, the cricothyroidotomy was converted to a tracheostomy, and the patient recovered well postoperatively without complication.

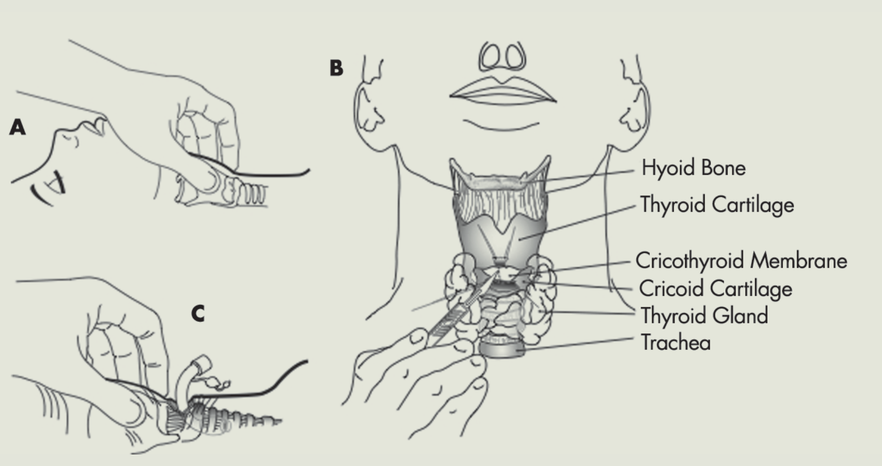
Courtesy David Leeson, *The Dallas Morning News*

TEACHING POINTS

1. This case provides an example of a patient who required an emergency surgical airway. The patient was able to maintain adequate oxygen saturation until arrival at a level III (see Prologue) medical treatment facility that had an experienced surgical staff. If this patient had been unconscious, it is likely that a surgical airway might have been needed at the site of injury.
2. Cricothyroidotomy is a simple procedure that is typically performed in a stressful environment. The procedure is taught to nonsurgeons working at a level I or level II medical treatment facility (see sidebar on page 25).
3. Tracheostomy should be avoided in this scenario because it is a multistep procedure that includes dividing strap muscles and dividing or elevating the thyroid isthmus. The patient, who cannot be preoxygenated, might not survive the additional time needed to perform a tracheostomy.

STEPS OF SURGICAL CRICOTHYROIDOTOMY

1. Identify cricothryroid membrane between cricoid cartilage (or cricoid ring) and thyroid cartilage (A).
2. Prep skin widely.
3. Grasp and hold trachea, stabilizing the airway.
4. Make a vertical skin incision down to the cricothyroid membrane (use a no. 10 or no. 11 blade).



5. Bluntly dissect the tissues to expose the membrane.
6. Make a horizontal membrane incision (B).
7. Open the membrane with forceps or the scalpel handle.
8. Insert a small, cuffed endotracheal tube (6.0–7.0 inner diameter) to just above the balloon (C).
9. Confirm tracheal intubation.
10. Suture the endotracheal tube in place and secure it with ties that pass around the neck.

4. Ten to fifteen percent of battle casualties present with maxillofacial trauma. Although establishing an emergency surgical airway is well within the capabilities of a general surgeon, complex maxillofacial reconstruction is not. This case demonstrates the need for an oral and maxillofacial surgeon or equivalent at the level III medical treatment facility.
5. This case also shows the not infrequent need for definitive reconstructive surgical procedures to be performed at the CSH.

CLINICAL IMPLICATIONS

Cricothyroidotomy is the procedure of choice for emergent surgical airway management. Indications for cricothyroidotomy include the following:

1. Maxillofacial trauma that precludes intubation.
2. Inability to secure the airway for any reason in hypoxic patients.

A nasopharyngeal airway (NPA) may be an alternative to surgery in the emergent management of oral and maxillofacial injuries.

Figure 1. *Patient transported to the CSH in a sitting position. This position allowed the patient to maintain his own airway until experienced trauma personnel could secure his airway.*

FIGURE 2. *Radiograph of a comminuted mandible fracture. Note cricothyroidotomy.*

Contraindications to an NPA: Coagulopathy, midface trauma, basilar skull fracture, and suspected elevated intracranial pressure.

DAMAGE CONTROL

Cricothyroidotomy is an essential damage control technique used to secure an airway that cannot be orally intubated. An endotracheal tube (6.0–7.0 inner diameter) or a tracheostomy tube (no. 4 or no. 6 Shiley tracheostomy tube) can be used.

FIGURE 3. *Patient immediately after cricothyroidotomy.*

SUMMARY

This patient required an emergent surgical airway. Medical personnel deployed to combat environments must be trained to perform surgical airways at the site of injury. Cricothyroidotomy is the surgical procedure of choice.

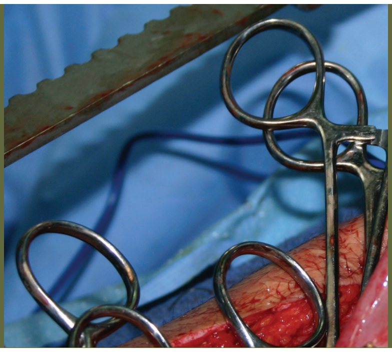
FIGURE 4. *Patient immediately post-op. The cricothyroidotomy was converted to a tracheostomy within 48 hours.*

SUGGESTED READING

Chapter 5: Airway/breathing. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 13: Face and neck injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 22: Soft-tissue injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.



I.3
Devastating Burn, Blast, and Penetrating Injury

CASE PRESENTATION

On admission, this male patient presented with burns covering approximately 60% of his total body surface (Fig. 1). The mechanism of injury was unclear. He received initial care (including intubation because of face and neck burns) and was evacuated to a level III medical treatment facility (combat support hospital [CSH]) that had been established in an austere environment. His oxygenation status remained poor despite intubation and supplemental oxygen. The patient was also tachycardic and hypotensive. Chest wall escharotomies were performed because of decreased chest wall compliance. Aggressive fluid resuscitation was initiated. No gross extremity deformity was noted. However, closer inspection of his left posterolateral chest revealed a fragment wound. Despite fluid and blood infusion, the patient became more hypotensive until all pulses were lost. In the presence of penetrating chest injury and witnessed loss of vital signs, resuscitative thoracotomy was indicated and performed. Open cardiac massage was performed, and resuscitation was successful. Thoracotomy revealed that the left diaphragm had been traversed by the fragment. Consequently, the patient underwent laparotomy in which splenic, gastric, and hepatic injuries were found. Expeditious splenectomy and closure of stomach wounds were performed. The patient required 14 units of blood. He had lost much of his body heat due to the combined effects of burns, fluid resuscitation, thoracotomy, and laparotomy. Despite active rewarming and other aggressive, lifesaving efforts, the patient died.

TEACHING POINTS

1. Combat trauma patients may sustain any combination of penetrating, blunt, and thermal injuries as a result of blasts from explosive munitions. Injuries depend on the proximity of the individual to the detonation.
2. Explosive munitions have three mechanisms of injury (Fig. 2); all mechanisms were present in this patient because he was in close proximity to the epicenter of the explosion:

   a. A burn covering approximately 60% of his total body surface.
   b. Evidence of a primary blast injury to the lungs (as observed during resuscitative thoracotomy).
   c. A thoracoabdominal fragment injury (evidence of a ballistic injury).

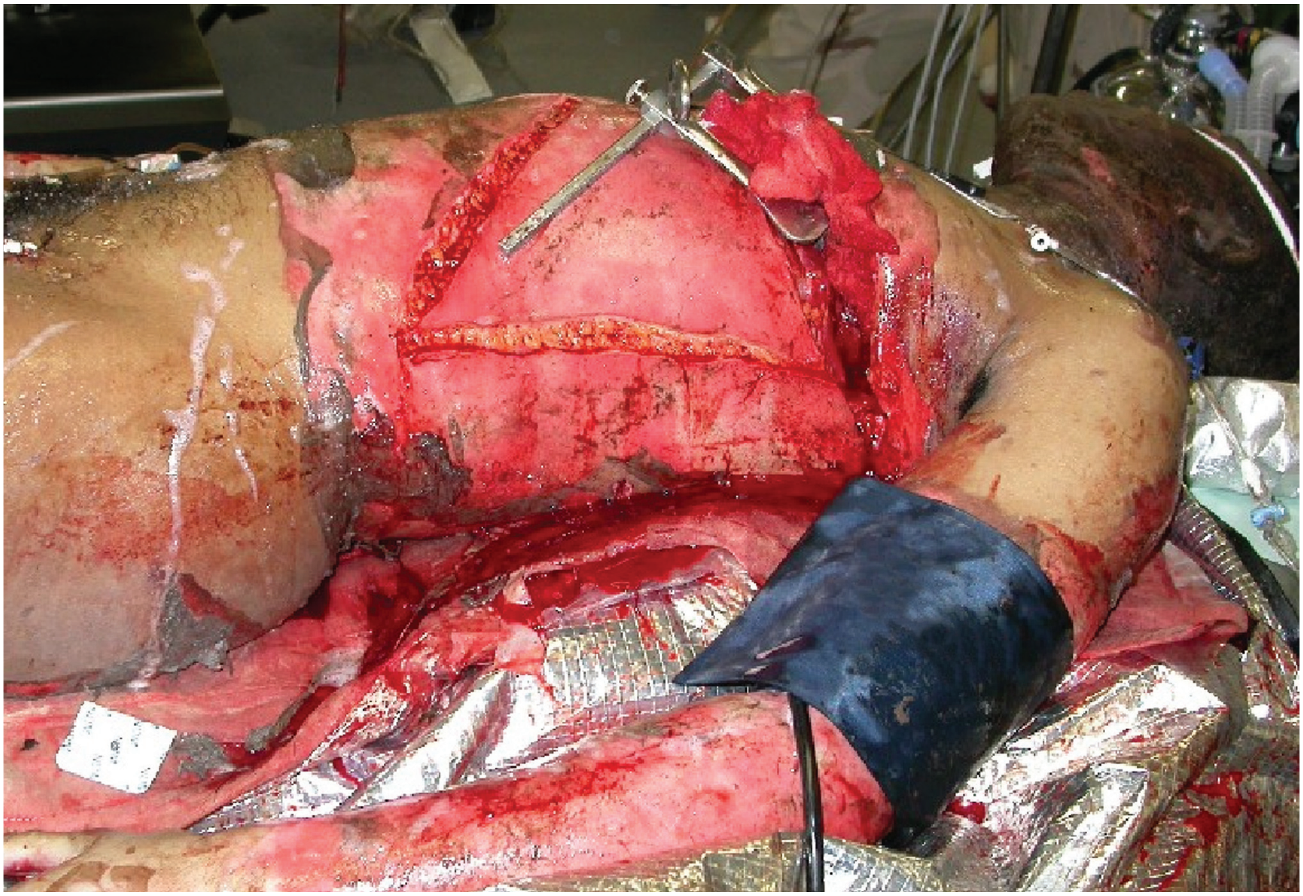


FIGURE 1. *Patient after resuscitative thoracotomy (but before laparotomy) for thoracoabdominal fragment injury.*

CLINICAL IMPLICATIONS

Identifying all weapon effects is not easy. Consider the following points:

1. Thermal injury is usually easily identified, but blast injury is not obvious on superficial examination.
2. The ears, lungs, and gastrointestinal tract are at greatest risk for blast effects.
3. A major thermal injury can obscure a penetrating wound.
4. Thorough secondary survey is mandatory to avoid missing life-threatening injuries resulting from explosive munitions.
5. Trauma patients with burn injuries, who do not respond to fluid resuscitation, must be reassessed for missed injuries.

DAMAGE CONTROL

The use of resuscitative thoracotomy in the combat zone should be limited to patients in extremis with penetrating thoracic injuries and then only under the most favorable circumstances (eg, small penetrating injury, minimal associated injuries, abundant resources, no other urgent patients). Even in these circumstances, patient salvage is rare. In this case, in which a laparotomy was required for control of ongoing bleeding, the absolute minimal intervention (packing, bowel stapling, ligation of bleeding vessels) is essential.

SUMMARY

This case demonstrates a common difference between combat trauma and civilian trauma. Civilian trauma is typically characterized as penetrating or blunt injury. Combat-injured patients often present with combinations of penetrating, blunt, and thermal injuries. As in civilian trauma, combat-injured patients require thorough secondary surveys to ensure that all life-threatening injuries are identified early in the resuscitation phase. Decisions to forego or undertake basic, aggressive resuscitative efforts, as in this case, are always difficult and include considerations of

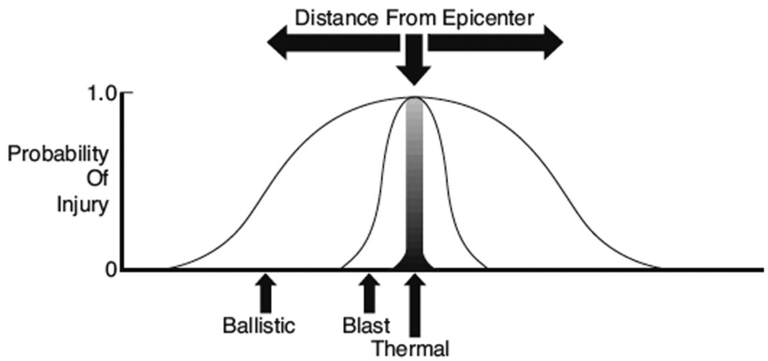


FIGURE 2. *Combat blast injuries often depend on the proximity of the individual to the detonation. In the case examined here, the patient was in close proximity to the epicenter of the explosion.*

INDICATIONS FOR EMERGENCY THORACOTOMY

- Penetrating thoracic trauma.
  - Traumatic arrest with previously witnessed cardiac activity (pre-hospital or in-hospital).
  - Unresponsive hypotension (blood pressure < 70 mm Hg).
- Blunt thoracic injury.
  - Unresponsive hypotension (blood pressure < 70 mm Hg).
  - Rapid exsanguination from chest tube (> 1,500 mL).
- Suspected systemic air embolism.

CONTRAINDICATIONS FOR EMERGENCY THORACOTOMY

- Blunt thoracic injuries with no witnessed cardiac activity.
- Multiple blunt trauma.
- Severe head injury.
- Severe multisystem trauma.

triage, resource availability, nature of the injuries, and individual expertise.

SUGGESTED READING

Chapter 3: Triage. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 16: Thoracic injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 28: Burns. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

I.4
To Shunt, Repair, or Amputate . . . ?

CASE PRESENTATION

A 23-year-old male sustained multiple blast injuries while riding in a bus when an improvised explosive device (IED) was detonated. The patient arrived at the Emergency Medical Treatment (EMT) section of a combat support hospital (CSH) unit approximately 65 minutes after the attack. He was incoherent and hypotensive on arrival, with a temperature of 97.2°C and a heart rate of 120 beats per minute. His injuries included an open right mandibular fracture, an open right first metacarpal fracture, an open left foot wound, and a large through-and-through medial left thigh wound with a large soft-tissue defect and arterial bleeding. No tourniquet was present, and an attendant was holding direct pressure on the wound. No evidence of left femur fracture was present, and minimal bleeding was noted from the hand, foot, and facial wounds.

PREOPERATIVE ISSUES

1. Obvious arterial injury (likely superficial femoral artery [SFA]).
2. Hypotension/hypovolemia.
3. Associated extremity injuries.

After initial resuscitation via large-bore IVs, the patient was taken to the operating room (OR). A right internal jugular cordis was inserted. Both extremities were prepped while pressure was maintained on the left thigh point of hemorrhage. His initial hematocrit was 24%. Exploration of the wound revealed near transection of the SFA and transection of the femoral vein. Atraumatic clamps were applied to gain proximal and distal control of the SFA, and the vein was ligated. Bleeding was effectively stopped following these measures.

DECISION POINT

Repair vascular injury vs shunt vascular injury vs primary amputation

Given the patient's hemodynamic stability with ongoing resuscitation and the cessation of significant bleeding, arterial repair with an interposition of reversed femoral vein was performed. The anesthesia team administered 4 units of packed red blood cells during the repair, and the laboratory prepared

4 units of fresh frozen plasma (FFP). Palpable pulses were not present, but an intraoperative arteriogram revealed flow to the foot. After release of the clamps, the patient demonstrated clinical evidence of coagulopathy by diffuse bleeding, and his blood pressure dropped. This condition was treated with additional warmed crystalloid and 2 units of whole blood; a shortage of FFP and difficulties thawing the available plasma precluded transfusion of concentrated factors. The patient's coagulopathy and acidosis worsened, and efforts to staunch nonsurgical bleeding from transected muscle and wound edges were unsuccessful. His body temperature fell to 34°C, and acidosis and hypotension did not respond to resuscitation. A damage control approach was taken: efforts to halt bleeding were aborted, all wounds were packed, a dopamine drip was initiated, and the patient was taken to the intensive care unit (ICU). Because no standard active warming devices were available, an improvised heater resembling a Bair Hugger was constructed using biohazard bags and a space heater. The patient received additional warmed whole blood and FFP; and sodium bicarbonate was also administered. Hypotension worsened and an epinephrine drip was started. His blood pressure could not be maintained despite additional pressors, and he became asystolic soon afterward. Further advanced cardiac life support measures were unsuccessful; and, despite aggressive resuscitative efforts, the patient died.

LEARNING POINTS

1. Before undertaking vascular reconstruction, all aspects of the patient's status (hemodynamic, coagulation parameters, urine output, and core body temperature) should be evaluated to determine if repair can/should proceed at that time. Not all of these data were or will be simultaneously available. Once a vascular repair has begun, it becomes difficult to break the operative flow and consider additional information (current core temperature, trend in coagulation parameters, response to ongoing resuscitation). It also becomes psychologically difficult to stop a repair once it has been initiated. Therefore, it is critical to communicate effectively with the anesthesia staff and to accurately assess the patient's condition before making the decision to repair, shunt, or amputate.
2. Hypothermia can be insidious but deadly, and can contribute to coagulopathy and acidosis. In this case, the OR heater was inoperable long after the case had started. Improvised active heaters, fluid warmers, and other adjuncts (IV bags warmed in a microwave and placed alongside the body, etc) should be used when standard equipment is unavailable.
3. The release of clamps after a vascular repair can severely impact a patient who was previously stable. Communication with the anesthesia staff to warn them of the impending return of flow (with potassium, metabolic acids, and inflammatory mediators) can help them prepare for the hemodynamic sequelae of clamp release. Do not assume that the anesthesia personnel are aware of the surgeon's actions or intentions.

SUMMARY/DAMAGE CONTROL

In retrospect, this patient's chances of survival would have been significantly improved if the SFA had been shunted or ligated and damage control had been implemented by packing the soft-tissue wounds and moving the patient to the ICU for resuscitation and warming.

SUGGESTED READING

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Chapter 22: Soft-tissue injuries. In: *Emergency War Surgery, Third United States Revision.* Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 23: Extremity fractures. In: *Emergency War Surgery, Third United States Revision.* Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

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Chapter 27: Vascular injuries. In: *Emergency War Surgery, Third United States Revision.* Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

I.5 Extremity Trauma With Profound Shock

CASE PRESENTATION

A US serviceman on a secure compound was within 10 feet of the impact point of a large mortar round and suffered severe injuries. He remained conscious and had an adequate airway despite severe bleeding that could not be completely controlled at the scene with direct pressure. He was transported immediately to a combat support hospital (CSH) that was less than a mile away. In the resuscitation area, pressure that was applied at the wounding scene was maintained by medical personnel despite minimal bleeding. He had sustained severe extremity and soft-tissue wounds, including a traumatic amputation of the right hand, a left arm radial artery injury with soft-tissue injury to the hand, a near amputation of the left leg, and severe injuries to the right leg (Fig. 1). The patient underwent rapid resuscitation by the assembled trauma team, which included emergency room and critical care physicians, nurses, medics, surgeons, and anesthesia providers. He was intubated, a right subclavian central line was inserted, and 4 units of packed red blood cells (PRBCs) were rapidly transfused. The walking blood bank was activated immediately so that fresh whole blood would be available within 45 minutes. The patient was transported immediately to the operating room (OR), where his resuscitation continued (Fig. 2). An end femoral artery arterial line was placed because no other sites were immediately available. His initial arterial line pressure was 80/40 mm Hg. The near amputation of the left leg was completed, requiring a hip disarticulation. Because of the extensive soft tissue, bone, nerve, and vascular damage to the right leg—as well as the patient's critical condition—a transfemoral amputation was performed quickly. A rapid laparotomy was done and a loop colostomy fashioned. The right arm stump was debrided, as was the soft-tissue injury to the left thenar eminence. The left radial artery, which now began to bleed profusely, was ligated after it was clear that the hand was adequately perfused by the ulnar circulation. Wounds were dressed by sponges held in place by stapling expandable mesh dressing to the skin (Fig. 3). The patient's intraoperative hematocrit (after the initial 4 units of PRBCs) was 15, and he was transfused with additional units of fresh whole blood that were available. He was taken to the intensive care unit (ICU) where warming and further resuscitation were continued. Once stable, the patient was evacuated by a standby Critical Care Air Transport Team to the level IV medical treatment facility in Landstuhl, Germany. After

FIGURE 1. *Patient at arrival to the Emergency Medical Treatment (EMT) area. Note direct pressure applied to the transected ends of both femoral arteries.*

a brief stopover, he was evacuated to a level V medical facility in the United States, where he arrived just 36 hours after leaving the CSH (Fig. 4). After multiple surgical procedures and extensive rehabilitation (Figs. 5 and 6), he was medically retired and is currently fully employed (Fig. 7).

CLINICAL IMPLICATIONS

1. Because of the relative youth of most combat casualties, the initial vital signs (heart rate, blood pressure) and ongoing bleeding may not alert the resuscitation team to the degree of hypovolemic shock at initial presentation. Immediate recognition of profound shock in severe combat injuries, particularly those created by large explosions (improvised explosive devices [IEDs] and mortar/artillery munitions), is critical to patient survival.
2. Patients who arrive with massive injuries (traumatic amputations; open abdominal or chest injuries; large, soft-tissue wounds of multiple extremities) are in profound shock virtually at the moment of wounding and require aggressive, immediate resuscitation (see end-of-chapter Commentary).

TEACHING POINTS

1. Severely wounded patients with multiple areas of injury benefit from a team approach to trauma care. From the initial scene of wounding through resuscitation, surgery, stabilization, and critical care in the ICU, through continuation of critical care during evacuation and definitive care and rehabilitation, an experienced team of healthcare providers offers the greatest chance of survival and functional outcome for those who suffer from war wounds. Teams at each level of care, as well as the entire team of the military healthcare system extending from the battlefield to stateside medical centers, are critical to patient survival and outcome.

FIGURE 2. *Patient in OR.*

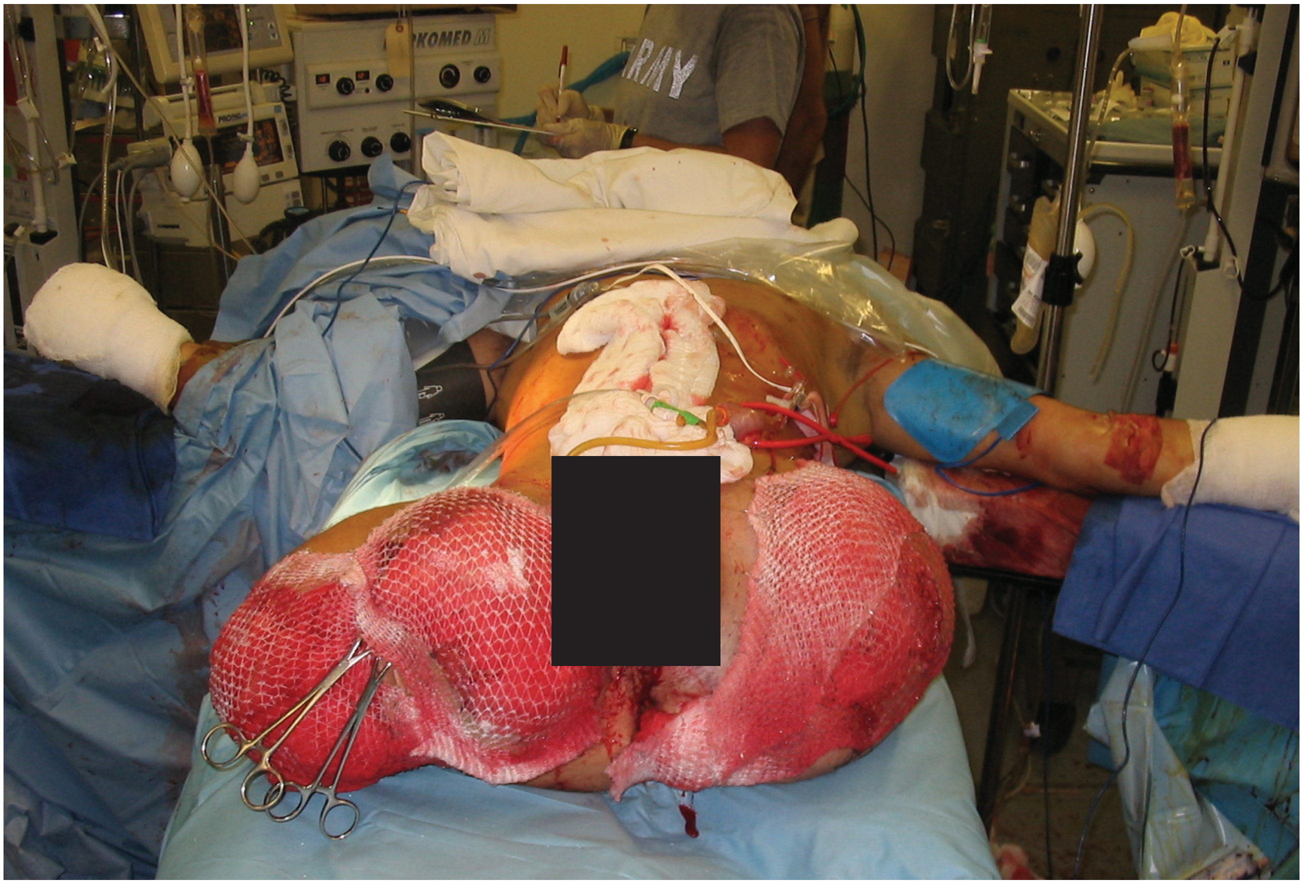

FIGURE 3. *Immediately post-op.*

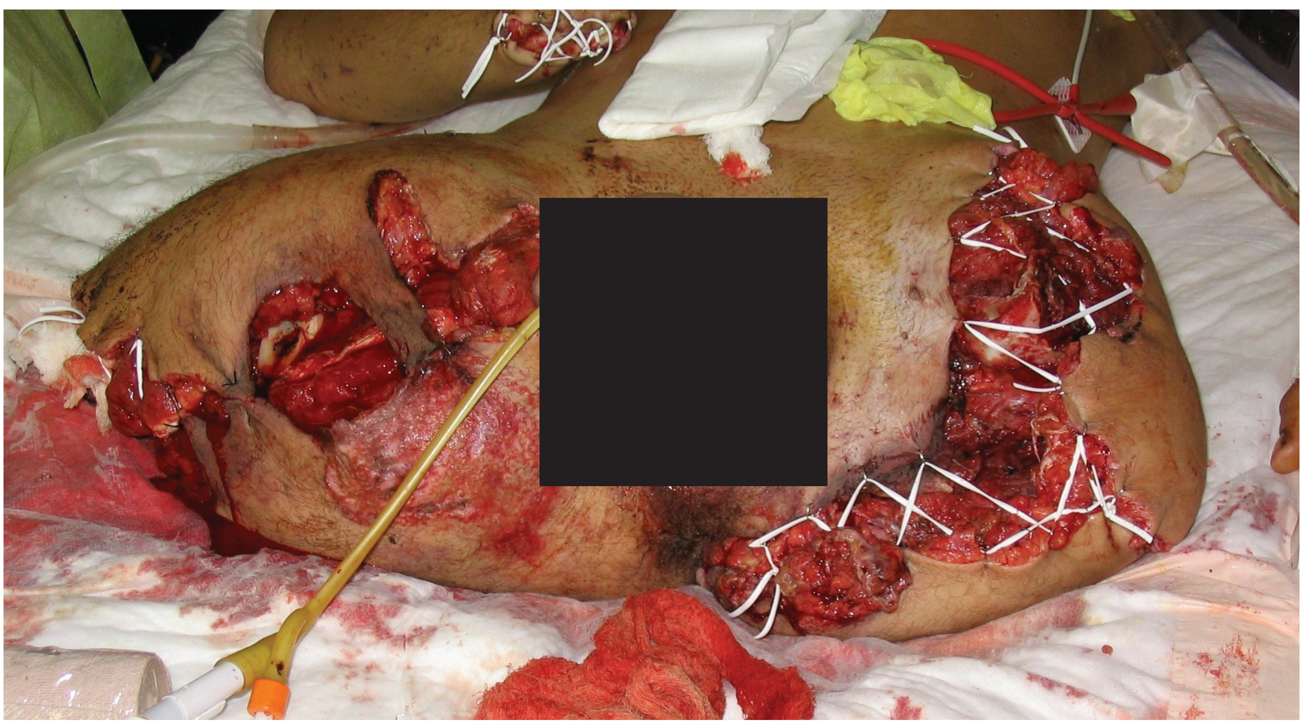

FIGURE 4. *Patient at Walter Reed Army Medical Center during initial examination.*

FIGURE 5. *Several months after wounding during rehabilitation.*

2. In the deployed setting, the OR is often the best location to resuscitate a patient with severe wounds, allowing excellent 360-degree patient access to multiple providers, superior airway control (anesthesia personnel), monitoring, temperature control, and pain control. Even if a surgical procedure is not needed, or deferred because of damage control considerations, the patient can be assessed quickly and resuscitation initiated in this location.

DAMAGE CONTROL

1. In the face of severe hemorrhage and extensive tissue injury, hypothermia, coagulopathy, and acidosis are ever-present threats to patient survival. An early decision for damage control—using abbreviated surgery with the goal of controlling hemorrhage, stopping contamination, and removing nonviable tissue—often proves to be critical to a favorable outcome.

FIGURE 6. *Further rehabilitation.*

2. Once the patient achieves physiological stability in the ICU, a return to the OR for further definitive surgery can be considered. In addition, patients may be transported to a higher level of care once stabilized, as in this case.

SUMMARY

Extensive combat wounds often result in profound shock, requiring immediate assessment, recognition, and resuscitation. Having an experienced trauma team assembled and prepared is critical to patient survival. Resuscitation in the OR offers many advantages for a critically injured patient over that available in a crowded resuscitation area. An early decision to use damage control techniques, based on the patient's physiological condition, is often the most important link to avoiding the deadly triad of hypothermia, coagulopathy, and acidosis. The "chain of custody" for the wounded patient—from the point of wounding

FIGURE 7. *Approximately 2 years after wounding.*

COAGULOPATHY

Clinical evidence of coagulopathy may be seen as "microvascular bleeding," a diffuse bleeding from surgically cut or traumatically damaged tissue surfaces, and bleeding from mucosal surfaces and around intravascular catheters. Laboratory evidence of coagulopathy is often said to be elevated prothrombin time (PT) or partial thromboplastin time (PTT), without specifying how much elevation. Published guidelines suggest using a cutoff of 1.5 times normal (midrange of PT reference or upper end of PTT). The suggested dose of fresh frozen plasma to correct coagulopathy is 10 to 15 mL/kg of patient body weight, usually 4 to 6 units of fresh frozen plasma for the average adult.

The use of the international normalized ratio (INR) is not advocated. The INR was developed and validated with respect to anticoagulation with coumadin. In any event, the PT value is arbitrary. It should be recognized that the PT value is a crude evaluation of a complex hemostatic system.

on the battlefield, through resuscitation, initial surgery, further resuscitation, critical care transport to definitive care, and final rehabilitation—requires a global team effort provided by the US military.

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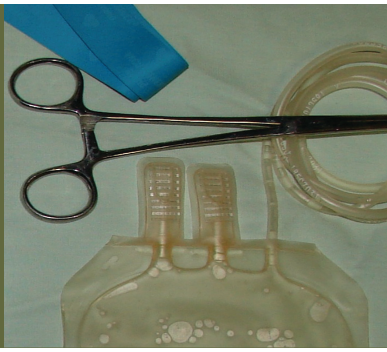


I.6 Massive Blood Transfusion in a Patient With Hemoperitoneum

CASE PRESENTATION

A Forward Surgical Team (FST) in remote Afghanistan was notified approximately 30 minutes prior to the arrival of a 24-year-old US soldier with multiple AK-47 gunshot wounds. The patient was reported to be tachycardic, hypotensive, and in severe distress. A whole blood drive was initiated immediately, and 4 units of fresh frozen plasma (FFP) were thawed in preparation for an anticipated requirement for massive transfusion. On arrival, the patient was noted to have been shot through the right chest, and the right and left lower extremities. He arrived tachycardic with a heart rate of 150 beats per minute and a blood pressure of 90 systolic with an obviously distended abdomen. He had a 14-gauge needle thoracostomy in the second intercostal space of the right chest. Resuscitation with packed red blood cells (PRBCs) and FFP was initiated immediately, and a chest tube was placed in the right chest with little return of blood. A right subclavian cordis was placed, and the patient was taken to the operating room (OR) for exploratory laparotomy. Prior to induction with general anesthesia, a Foley catheter was placed, and he was prepped with betadine solution from the neck to the ankles. The surgeons and assistants were gowned, and the patient was draped in anticipation of a profound drop in blood pressure after induction. The patient's blood pressure dropped to 70 systolic at induction. The abdomen was rapidly opened through a midline incision, and massive hemoperitoneum was encountered. All four quadrants were immediately packed. The hemoperitoneum was the result of severe injuries of the liver, duodenum, stomach, colon, and segmental mesenteric arteries. Pulsatile bleeding from the mesenteric arteries was rapidly controlled by ligation. The packs were then removed from the liver. A large, grade 4, stellate laceration could not be controlled by packing. Therefore, a Pringle maneuver was performed, and the large, segmental hepatic veins were identified and eventually controlled with ligation using suture and surgical clips. During this portion of the operation, blood loss was significant. The patient ultimately received 12 units of fresh whole blood (FWB), 12 units of PRBCs, 13 units of FFP, 5 units of cryoprecipitate, and 7.2 mg of recombinant Factor VIIa. With the liver bleeding controlled, the liver was packed and the patient's heart rate almost immediately decreased. His blood pressure normalized. Laboratory values at the time of the patient's most profound shock were significant for a base deficit of 14. The stomach and duodenal injuries

PLASMA

Plasma for transfusion is obtained from volunteer human donors by collection into bags with an anticoagulant preservative mixture. The plasma, or noncellular portion of the blood, is usually separated by centrifugation of a whole blood unit, but can be separated by filter or centrifugation using an automated device. The procedure, known as apheresis, can collect as many as 3 times the volume of plasma as that obtained from a single unit of whole blood, while simultaneously returning the cellular component to the donor.

Plasma has been used to treat the combat-injured since World War II. Historically, the initial intent was to use it as a colloid for volume replacement. However, its usefulness to replace coagulation factors in bleeding patients with factor deficiency has been advocated in routine civilian practice for trauma and nontrauma conditions. There is little scientific evidence supporting the practice or to suggest the best practice. However, it seems rational that, in a patient with laboratory or clinical evidence of coagulopathy associated with bleeding, replacement with plasma may correct the factor deficiency and reduce bleeding.

Plasma is separated from the cellular portion of blood and frozen (fresh frozen plasma) within 8 hours of collection. Because of the sometimes long distances between organized blood drives and the fixed facilities with equipment for separation and freezing, the 8-hour requirement cannot always be met. In this case, separation of the plasma still occurs within 8 hours, but freezing may occur up to 24 hours after collection. Either variety, once thawed before transfusion, has essentially the same concentrations of key plasma proteins. These two varieties are similar to liquid plasma never frozen. There is a very small decrement in Factor V concentration and a larger decrement in Factor VIII when stored as a liquid over time. Refrigeration slows the degradation of plasma proteins, and coagulation factors remain little changed for as long as 5 days. Therefore, any of these types of plasma, kept liquid and refrigerated up to 5 days, can be used for the same indications. (The exception is use of the stored plasma for Factor V replacement. This use is not relevant for treating the coagulopathy of a trauma patient.)

The details of collection, processing, and storage may differ, but the different variations produce little significant clinical variation overall. Each unit of plasma has much the same concentration of plasma proteins as normal plasma, and the variation from unit to unit is that of normal human variation. Keeping in mind unit-to-unit variation, plasma as a single unit of fresh frozen plasma has the following qualities:

- Overall volume: 190–220 mL (includes about 25 mL of anticoagulant preservative).
- Coagulation factors, including anticoagulants and fibrinolytic activity in normal concentrations.
- Plasma proteins, including antibodies, notably the red cell major group (ABO) isohemaglutinins, an antibody that is usually and predictably present based on the donor's blood type:

Type A donor plasma:	anti-B.
Type B donor plasma:	anti-A.
Type AB donor plasma:	no anti-ABO.
Type O donor plasma:	anti-A, anti-B, anti-AB.

Consideration of ABO Type

Plasma from AB donors has no anti-A or anti-B, and should cause no direct incompatibility with the red cells of any blood type. Type O donor plasma has both anti-A and anti-B, and thus is incompatible with the majority of patients of the other types (A, B, and AB). Therefore, when the need for emergency plasma transfusion is infrequent, the choice of plasma for prethawing and emergency transfusion should be AB. However, when plasma is frequently transfused to patients without known ABO type, the use of AB plasma will quickly deplete the inventory, and AB recipients who need more plasma will not have any available.

When large numbers of plasma units are transfused, the best choice of type that balances resources with risk to recipient is **plasma of type A donors**. For those situations, type A plasma should be chosen for the prethawed emergent transfusion. Type A plasma is compatible with O and A recipients. Incompatible recipients (B and AB) make up a minority of the general population. Because the B antigen has weaker antibody affinity and is present in lower numbers on red cells than A, the anti-B in A plasma is less likely to cause problems in an incompatible recipient. Further mitigating immediate incompatibility due to transfused anti-B, plasma also contains the B (or A) antigen of a person's blood type. The B antigen in a recipient's plasma provides a neutralizing substance that reduces antibody availability to bind red cells.

The volume of incompatible plasma should be limited, because continued transfusion of incompatible plasma will eventually coat red cells and can cause hemolysis. Type-specific plasma should be given as soon as possible, and only the initial 2 units or so should be given as type A, prethawed.

Recent retrospective study of transfusion patterns and clinical outcomes in the Operation Iraqi Freedom and Operation Enduring Freedom (Afghanistan) conflicts suggests an approach, or a guide, to dosing fresh frozen plasma in bleeding patients with coagulopathy. In a retrospective comparison of red cell and plasma transfusion patterns and mortality, a packed red cell to plasma unit ratio of 1–2:1 was associated with the lowest mortality. (See sidebar on pages 44–45.)

Based on this observation and existing guidelines, the following recommendation is reasonable: For a patient with laboratory and clinical evidence of coagulopathy, the early use of plasma to treat bleeding may use a ratio of packed red cells to plasma of 1–2:1. However, the use of this ratio should <u>not</u> be applied for all patients, or any bleeding patient without coagulopathy. Such an unrestrained practice would contribute to a depletion of resources without expected benefit—a use of resources that should be reserved for the coagulopathic patient with uncontrolled hemorrhage.

—Francis M. Chiricosta, MD, LTC, MC, US Army

FIGURE 1. *Patient immediately after stabilization surgery. The abdomen is open, and the extremity fractures have been splinted, deferring additional surgery until the patient is stable.*

were controlled with staples, and colon and bowel injuries were resected without creation of anastomoses. The abdomen was closed with a Bogota bag after being washed out with saline. The patient's extremity wounds were then rapidly assessed. Bleeding from the open wounds was controlled with chitosan dressings and packing, and his fractures were splinted (Fig. 1). He was taken to the post-op recovery area. Labs drawn in the immediate post-op period were significant for a base deficit of 3, with a hematocrit of 32%. The patient's heart rate was consistently less than 100, and his systolic blood pressure was consistently above 120 mm Hg. Within 1 hour of surgery, the patient was transferred to a level III military medical treatment facility for ongoing care.

TEACHING POINTS

In patients with massive hemoperitoneum shock, profound hypotension at the time of anesthesia induction and surgical opening must be anticipated. Meticulous attention to detail will allow the surgical team to respond to this predictable event.

1. Prepare (sterilely) and drape the patient prior to induction of anesthesia. The loss of sympathetic tone during induction will result in an acute drop in the patient's blood pressure. Opening the abdomen and releasing the peritoneal tamponade will exacerbate the hypotension. The requirement for blood products will likely increase during this time until the source of hemorrhage is controlled.
2. Establish effective intravenous access. Two large-bore intravenous catheters may be inadequate, and placement of a cordis central catheter should be strongly considered.
3. Begin the transfusion of blood products prior to surgery, if possible. Thaw FFP, and call for FWB or platelets as early as possible. Warm all fluids to 40°C and minimize crystalloid infusion. Use recombinant Factor VIIa with the initial transfusions.
4. Transfer the patient to the OR as soon as possible. This facilitates rapid entry into the chest or abdomen in the event of acute decompensation. Resuscitation of the shock trauma casualty should be considered an urgent OR event and should not be delayed by emergency room evaluation and resuscitative endeavors.
5. Control intraabdominal hemorrhage initially with tight packing of all quadrants. Then, address bleeding sites one quadrant at a time.
6. Place sponges (when packing the liver) in such a way as to approximate the fractured lobes of the liver and compress bleeding sites. This frequently requires posterior packing and may require mobilization of the liver to varying degrees. A Pringle maneuver may be helpful.
7. Note: When bleeding is arrested, rapidly control any source of peritoneal contamination from bowel injury. Do not attempt to create any anastomosis, and stomal creation is unwise. Pack the abdomen and leave the abdominal fascia open. Place a Bogota bag or wound VAC and plan to evacuate or return to the OR when the patient has stabilized.

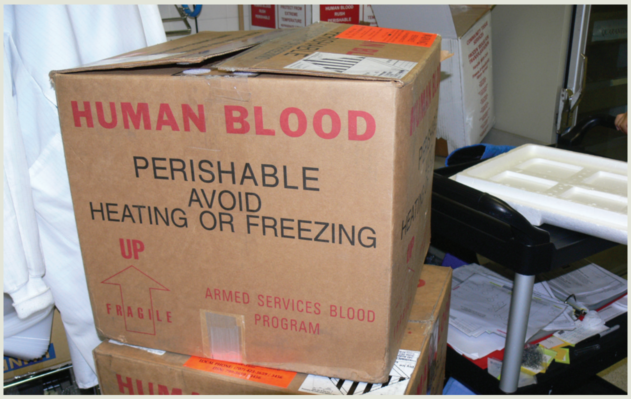
CLINICAL IMPLICATIONS

Uncontrolled hemorrhage remains the leading cause of potentially preventable death in the present conflicts in Southwest Asia. Massive transfusion is administered to approximately 7% to 8% of combat casualties. Combat surgeons must be familiar with the blood product resources available to them, and they must also be experts in the administration of blood products and know the indications for their use. In austere environments, blood products are available in varying amounts; but, trained blood bank technicians may not be available, thus leaving the physician completely responsible for the safe administration of this lifesaving resource. When combat-wounded patients require transfusion, the following guidelines apply:

1. Begin resuscitation with PRBCs. If four or more units of PRBCs are required, transfuse FFP at a ratio (PRBCs:FFP) of 1:1 or 2:1. Minimize resuscitation with crystalloid, which can cause a dilutional coagulopathy.[1]
2. If massive transfusion (defined as 10 units or more of PRBCs) is anticipated, then platelets should also be administered. If platelets are not available, then FWB should be given.[2]
3. FWB is blood that has been recently drawn. It provides red blood cells, plasma, clotting factors, and platelets. One unit of FWB is the equivalent of 1 unit of PRBCs and 1 unit of FFP. It contains the equivalent of 20,000 to 30,000 plts/cc.[3] FWB is indicated for use in an austere environment where component

PLATELETS vs FRESH WHOLE BLOOD IN MASSIVE TRANSFUSION

In the treatment of coagulopathy and bleeding in trauma patients, the use of plasma alone cannot always be effective. Progressive thrombocytopenia is associated with continued bleeding and transfusion. Platelet transfusion can be helpful.



Civilian trauma centers in the United States have available a variety of blood components to treat bleeding. Commonly used among these components are platelets. Conversely, although fresh whole blood (FWB) use is limited in the United States, the military routinely utilizes FWB in the setting of massive transfusion (MT) as both a source of platelets and other factors when large quantities of blood are required.

Surgeons have anecdotally reported rapid correction of microvascular bleeding after infusion of FWB. However, there are drawbacks and dangers to FWB transfusion that can be avoided or lessened by the use of separated platelets.

An emergency whole blood drive ("walking blood bank") requires the commitment of many healthcare workers and donors, taking them away from other duties at the precise time of high demand to treat trauma. Platelets, on the other hand, can be precollected at a scheduled time of the platelet collector's and donor's choosing. Freshly collected whole blood cannot be adequately tested for transfusion-transmitted disease. With platelet collections, donors can be tested ahead of time and once shown to be test-negative, a single donor can donate twice a week, providing many doses for treatment over the course of 2 months. A donor of whole blood can safely donate only 1 unit in that time, and it is not pretested. The ABO type of whole blood must be type-compatible with the recipient. Safe practice (typing of the donor, ensuring the unit is labeled with that type, typing the recipient, and ensuring that the correctly typed unit goes to the correctly typed recipient) is a many-step process with a high likelihood of error in a stressful emergency or mass casualty setting. The type compatibility of a platelet unit can be obtained carefully and double-checked in the quiet between emergencies. ABO-incompatible platelet transfusion is much less likely to cause a fatal hemolytic reaction than an incompatible whole blood transfusion.

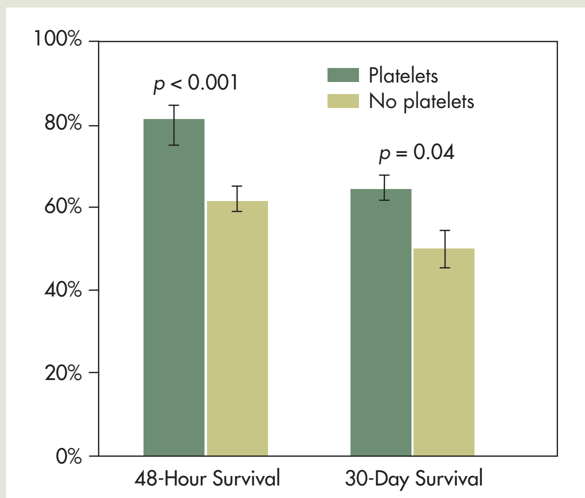


FIGURE 1. *48-hour and 30-day survival by platelet vs no platelet groups. Groups compared using chi-square. Forty-eight-hour survival: platelet group—218/266, 82 ± 2%; no platelet group—90/137, 66 ± 3%; $p < 0.001$. Thirty-day survival: platelet group—121/196, 62 ± 4%; no platelet group—53/107, 50 ± 5%; $p = 0.04$.*

In a study of transfusion patterns and outcomes in Operation Iraqi Freedom/Operation Enduring Freedom (performed by MAJ Jeremy Perkins), the use of whole blood or the use of apheresis platelets (aPLTs; collected in theater) in massively transfused patients resulted in lessened mortality than in patients without the use of either. The outcome was similar whether whole blood or platelets were used (in addition to packed red cells and plasma). Because platelet units maintain usefulness and safety only if stored for less than 5 days, and given the long time it takes to transport supplies from the United States to a deployed military medical treatment facility in theater, if platelets were to be transfused in Iraq and Afghanistan by US medical treatment facilities, they would have to be collected in theater.

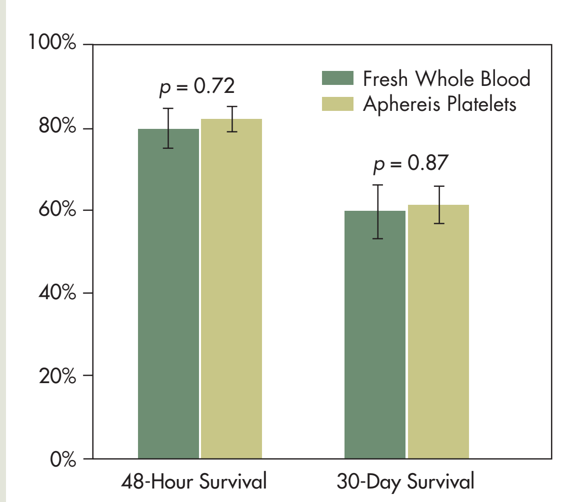


FIGURE 2. *48-hour and 30-day survival by FWB vs aPLT groups. Groups compared using chi-square. Forty-eight-hour survival: FWB—56/70, 80 ± 5%; aPLT group—143/174, 82 ± 3%; p = NS. Thirty-day survival: FWB—36/60, 60 ± 6%; aPLT group—72/117, 62 ± 5%; p = NS. NS: not significant.*

In November 2004, the combat support hospital (CSH) in Baghdad, Iraq, acquired the capability to collect (by apheresis) and provide platelets (aPLTs) onsite. This offered a unique opportunity to compare not only outcomes of patients managed with and without platelets, but also to compare outcomes for patients who received FWB as compared with those receiving aPLTs. Records for trauma admissions to the CSH in Baghdad between January 2004 and December 2006 who required an MT were reviewed. MT, defined as transfusion of 10 units of packed red blood cells and/or FWB in 24 hours, was administered to 708/8,618 (8.2%) trauma admissions. Of the 708 requiring MT, records were available for 535 patients. Of these, another 101 patients were excluded because they were managed at Forward Surgical Team (FST) facilities or did not receive total transfusion in the first 24 hours. Of the remaining 434 patients, 285 received platelets either as FWB or as aPLTs, and 149 patients received no platelets (neither FWB nor aPLTs). Forty-eight-hour (82% vs 66%, $p < 0.001$) and 30-day (62% vs 50%, $p = 0.04$) survival were higher in patients receiving platelets, compared with those who did not receive platelets (Fig. 1). Analysis of FWB and aPLT subgroups showed no differences for 48-hour (80% vs 82%, $p = 0.7$) or 30-day (60% vs 62%, $p = 0.9$) survival (Fig. 2). Multivariate logistic regression was performed and showed that both FWB and aPLTs were independently predictive of survival. In this regression, higher fresh frozen plasma/red blood cell ratios were independently predictive of improved survival at 48 hours, consistent with data published by Borgman et al.[1]

Transfusion of platelets either in the form of aPLTs or FWB is associated with improved survival in patients requiring MT. There do not appear to be survival differences between patients managed with FWB, compared with aPLTs (in addition to packed red blood cells and plasma). Because of an easier collection process and its better safety profile, the use of platelets as part of the transfusion treatment of coagulopathy and bleeding should be preferred over the use of whole blood when the former is available.

At facilities where aPLTs or other blood components are unavailable, FWB is an acceptable alternative for the management of coagulopathy in patients requiring MT.

—MAJ JEREMY PERKINS, MD, AND FRANCIS M. CHIRICOSTA, MD

1. Borgman MA, Spinella PC, et al. The ratio of blood products transfused affects mortality in patients receiving massive transfusions at a combat support hospital. *J Trauma*. 2007;63:805–813.

FIGURE 2. *Whole blood donation set that has been prepared for the eventuality of the requirement for fresh whole blood.*

therapy is not available. In the current operating environments in Southwest Asia, it is primarily used by level II FSTs to provide platelets in patients requiring massive blood transfusions. It may also be used in lieu of PRBCs, FFP, and cryoprecipitate when these components are in short supply or exhausted.

4. Prior to the present conflicts in Southwest Asia, FWB transfusion was considered nondoctrinal. Training small units, such as FSTs, the technique of drawing and administering blood was not done despite the frequent use of FWB in previous conflicts. Special equipment is required, such as single donor collection bags and blood tubes (Fig. 2), and a centrifuge is required to prepare blood tubes collected for viral testing prior to shipment.
5. The primary concern with the use of FWB is the risk of infectious disease transmission. US service members are prescreened for human immunodeficiency virus (HIV) and are vaccinated for hepatitis B virus (HBV). However, they are not prescreened for hepatitis C virus (HCV), human T-cell leukemia, or syphilis. There is also the risk of transmission of local endemic diseases (eg, malaria). The risk of transmitting infectious disease is thought to be less than 1%, whereas the risk of dying from hemorrhagic shock is greater than 30% (unpublished data from the Joint Theater Trauma System Clinical Practice Guidelines for Fresh Whole Blood). Therefore, the use of FWB is indicated when pretested component therapy is not available. In combat patients who require massive transfusion, administration of platelets has been shown to improve survival. There is no significant difference in survival in patients who received apheresis platelets versus those who received platelets from FWB transfusion.[1] Rapid screening tests are available for blood type, HBV, HCV, syphilis, and HIV. These tests are not approved by the US Food and Drug Administration, but are still useful in prescreening donors when time permits and if personnel are trained in their use. Blood should be drawn from all donors for

EMERGENCY FRESH WHOLE BLOOD COLLECTION PROCEDURE

The Walking Blood Bank

1. Develop (when possible) a roster of prescreened donors. In all cases, have the donors complete a DD Form 572—Blood Donation Record. Exclude high-risk donors. Prior blood donors have been screened previously for transmittable disease. Donors with recent laboratory confirmation of blood type are ideal, because identification tags (dog tags) are incorrect 2% to 11% of the time.
2. Clean the donor's arm with povidone-iodine or chlorhexidine solution for 1 minute.
3. Draw the blood from an arm vein into a single donor blood collection bag containing anticoagulant, such as citrate, phosphate, dextrose, adenine (CPDA) solution. Draw about 450 cc of blood until the bag is almost full.
4. Draw tubes of blood for typing and crossmatching (EDTA [ethylenediamine tetraacetic acid] purple top) and for testing of blood-borne infectious disease (two serum separator tubes, red and gray tops). The serum separator tubes should be centrifuged for 20 minutes prior to shipment.
5. Inform the operating team (before transfusing blood) that emergency draw fresh whole blood is about to be transfused and confirm blood type and pertinent patient history.
6. Document clearly who the blood was donated from and to whom it was transfused.
7. Obtain and follow any additional theater guidelines and policies for the transfusion of fresh whole blood.

Equipment Required for Fresh Whole Blood Collection (see Fig. 2)

- Blood recipient set (collection bag), indirect Tx Y-type.
- Stopcock, IV therapy three-way, with Luer.
- Serum separator blood tubes.
- EDTA blood tubes.
- Centrifuge.

posttransfusion testing. A record of donation should be kept for both the recipient and the donor in the event that postscreening testing reveals an infectious disease.

6. Type O PRBCs are the only blood type available to FSTs. Doctrinally, FSTs carry 20 units of PRBCs and have a blood refrigerator as organic equipment. FFP is not doctrinally used by FSTs. However, in the current (2007) operating environment, FFP and cryoprecipitate have been made available. This requires a nonstandard blood freezer and a plasma thawing unit. Type O-negative PRBCs are usually reserved for female patients. There is no absolute blood type match for FWB transfusion. However, because patients at the FST almost always receive several units of type O PRBCs before they receive FWB, usually type O FWB is transfused. Ideally, patients receiving FWB would receive type-specific blood. In local national patients and often in coalition forces, the patient's blood type is unknown and type O blood is used.
7. If ongoing bleeding is anticipated and recombinant Factor VIIa is indicated, then it should be administered early when the patient has a pH above 7.1 and is more likely to have adequate functioning coagulation factors.
8. At level II, there is no specifically trained medical director of the blood bank. The commander or surgeon is entirely responsible for the safe administration of blood products. There are many guidelines that attempt to instruct the surgeon on when the administration of whole blood is appropriate. In fact, the decision to administer FWB is a clinical decision that must be made before the onset of coagulopathy and

exsanguination. Allowing the patient to become coagulopathic prior to administering the appropriate blood products will almost always result in the death of the patient. The surgeon must anticipate a delay of up to 1 hour for the transfusion of FWB.

DAMAGE CONTROL

FWB is the most expeditious source of red cells, platelets, and clotting factors in the acute management of combat trauma. The need for massive blood transfusion must be determined early, sometimes before the patient arrives. If FWB use is likely, call for donors early and begin thawing FFP immediately.

SUMMARY

Hypotension and shock from blood loss remain common problems in battlefield trauma. Replenishment of blood either as components or FWB is fundamental to the successful treatment of these patients. All physicians deploying to a war theater must understand the basic principles of transfusion.

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COMMENTARY

Damage Control Resuscitation

by COL John B. Holcomb, MD

Although the vast majority of bleeding trauma patients who arrive in emergency departments (EDs) are either hypercoagulable, or only slightly injured with normal coagulation parameters, a small number of trauma patients (approximately 10%) are hypocoagulable (international normalized ratio [INR] > 1.5).[1,2] This minority constitutes about 50% of those who receive any blood products and represent the majority of in-hospital trauma deaths. Death increases threefold after receiving more than 4 units of blood. Patients are occasionally hypothermic and have acidosis-induced coagulation factor and platelet dysfunction, combined with coagulation factor consumption, culminating in a profound coagulopathy. Although it has been long recognized that the lethal triad of hypothermia, acidosis, and coagulopathy is associated with a significant increase in mortality,[3] coagulopathy has been viewed as a byproduct of resuscitation, hemodilution, and hypothermia. Based on civilian trauma and military combat casualty data, we now know that coagulopathy is, in fact, present on admission.[4–6]

Current resuscitation practice focuses primarily on rapid reversal of acidosis and prevention of hypothermia, whereas concurrent surgical interventions focus on controlling hemorrhage and contamination with sutures and packs. Early intravascular treatment of coagulopathy has been relatively ignored. Standard resuscitation methods are appropriate for the 90% of trauma patients who are not in shock and are hypercoagulable after injury.[7] However, for the 10% of patients who constitute the most seriously injured, are in shock, and are coagulopathic (hypocoagulable), plasma has been identified as the best resuscitation fluid.[8,9] Unfortunately, clinicians are still being taught never to use plasma as a resuscitation fluid.[10]

Recent studies have shown the following:

- Coagulopathy of trauma is present at a very early stage after injury.[1–6]
- Ringer's lactate solution and normal saline increase reperfusion injury and leukocyte adhesion.[11]
- Increased transfusion is associated with increased risks.[12]
- Massive transfusion in military and civilian casualties is associated with an increased risk of death.[13,14]

Taken together, these observations suggest that the most severely injured patients will likely benefit from a new resuscitation strategy focused on optimal timing and modulation of the metabolic, inflammation, and coagulation pathways.

Over the last 6 years, the US Army has gained considerable experience in resuscitation of combat casualties. Based on previous civilian clinical studies, recommendations of an international consensus conference on early, massive transfusion for trauma,[15] and the cumulative experience of experts in the current war, it is possible to rapidly identify patients at high risk for coagulopathy on admission and promptly treat hypothermia, acidosis, and coagulopathy (see Appendix D). This strategy, known as "damage control resuscitation," addresses the entire lethal triad immediately on admission in concert with aggressive hemostatic interventions.[16] Damage control resuscitation as a structured intervention begins immediately after rapid initial assessment in the ED and progresses through the operating room (OR) into the intensive care unit (ICU). Interventions directed at normalizing the INR, base deficit, and temperature included the following:

- Repeated point-of-care testing.
- Commercial warming devices.

- Use of multiple blood products.
- US Food and Drug Administration-approved drugs readily available in theater (albeit in new ratios and amounts).

Compared with civilian damage control surgery resuscitation strategies, deployed resuscitation efforts are largely completed in the OR, with little resuscitation required in the ICU. Achieving this goal quickly in the OR may ultimately allow a shift from limited damage control surgery to earlier, aggressive surgical interventions, including sophisticated limb salvage techniques and improved outcomes.

Damage control resuscitation consists of two parts and is initiated within minutes of arrival in the ED. First, resuscitation volume is limited to keep systolic blood pressure at approximately 90 mm Hg, preventing renewed bleeding from recently clotted vessels.[17–22] Second, intravascular volume restoration is accomplished by using thawed plasma as a primary resuscitation fluid in at least a 1:1 ratio with packed red blood cells (PRBCs).[8,9,23–25] Recombinant Factor VIIa may be used along with the very first units of red blood cells, thawed plasma, and platelets, if indicated by the clinical situation (see Clinical Practice Guidelines for Damage Control Resuscitation at Levels IIb and III [Appendix D]).[26] For casualties who will require continued resuscitation, the blood bank is notified to activate the massive transfusion protocol. This protocol results in the delivery of 6 units of plasma, 6 units of PRBCs, 6 packs of platelets, and 10 units of cryoprecipitate stored in individual coolers. For the most severely injured with refractory bleeding, fresh warm whole blood from the walking blood bank is resorted to as a primary resuscitative fluid.[27,28] Crystalloid use is significantly limited and serves mainly as a carrier to keep lines open between the units of blood products. The very first data from Iraq describing the initial implementation of this approach revealed a decrease in long-term mortality, from 65% to 19%, by using plasma in a 1:1 ratio with PRBCs.[29]

Damage control resuscitation is summarized then as:

- Early diagnosis of hemorrhage/hypovolemic shock in the ED.
- Early diagnosis and aggressive treatment in the ED of the lethal triad.
- A 1:1:1 ratio (thawed plasma:red blood cells:platelets) throughout resuscitation.
- ED/OR/ICU use of recombinant Factor VIIa, as needed.
- Massive transfusion protocol that delivers fixed ratios of products until stopped by the surgeon.
- Rapid use of fresh whole blood in most critical patients with ongoing hemorrhage.
- THAM (tris-hydroxymethyl aminomethane; also known as tromethamine) and Ca^{2+} in the OR to normalize ionized Ca^{2+} and keep the pH > 7.2.[30]
- Minimize crystalloid.[31,32]
- Allow hypotension until definitive (operative) hemorrhage control.

The recommendations described previously are a snapshot of "best in theater resuscitation practice" in June 2006. It is anticipated that these practices will be improved upon as new data are available. Progress in trauma care requires continuous improvement in everyday patient management, based on good clinical studies. Many of our most basic trauma care principles are founded on tradition rather than on evidenced-based best practice. Current resuscitation practices fall into this category, and only now are data emerging in the civilian trauma literature documenting the deleterious effects of aggressive crystalloid resuscitation.[31,32] As in past wars, observation, discussion, analysis, and recommendations from experienced military medics, nurses, physicians, and scientists—together with our civilian trauma colleagues—will provide the basis for new medical practice, grounded in appropriate and relevant preclinical and human studies.[33,34] Injury, procedure, and outcome data collated in the Joint Theater Trauma Registry will provide hypothesis-generating information for years to come. Further experience, research, development, and prospective randomized studies will generate new information and ongoing modifications.

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