MODERN WARFARE

Chapter 1

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Introduction

War has historically provided an opportunity for medical advancement and innovation. Military medical personnel face the challenge of managing a high volume of severe multisystem injuries, relative to what is encountered in civilian practice. Combat casualty care (CCC) providers face injury and illness in the context of an austere wartime environment, in which transport times may be unpredictable and supplies and staff limited. The frequency of multiple or mass casualties may overwhelm available resources. In addition, CCC providers not only care for injured members of the military, but for injuries and illnesses suffered by the local population and enemy combatants (Fig. 1).

Figure 1. *Level III Combat Support Hospital. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.*

Such challenges have fostered innovation in all aspects of CCC. Since 2001, significant changes including the organization of medical teams, new resuscitation practices, new technologies, and changes in evacuation strategies have been implemented. The creation of a database of all military casualties from the current conflicts in Iraq and Afghanistan, known as the Joint Theater Trauma Registry (JTTR), has allowed for an unprecedented level of analysis of wartime injuries and deaths. Such analysis has been used to identify potentially preventable causes of death and paved the way for implementation of new technologies and practices targeted towards reduction of morbidity and mortality from combat.[1,2]

> Combat casualty care providers face multiple challenges in wartime including an austere environment, limited supplies or staff, multiple-casualty-incidents, and caring for the local population or enemy combatants.

Comparing Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) to Vietnam, the mortality rate of combat-sustained injury has decreased by nearly half.[1] The survival rate in these conflicts exceeds 90 percent, which is higher than prior conflicts.[3,4] Wounding patterns in OEF/OIF differ from that of previous conflicts (World War II, Korea, Vietnam, and the Persian Gulf War), which had a higher proportion of thoracic injuries and fewer head and neck injuries.[5,6,7,8,9] There has been a decreased incidence of wounds to the abdomen since the Persian Gulf War.[10] The percentage of blast-related injuries is now higher.[9]

The resources and evacuation systems used to treat casualties have seen substantial improvements since the prior conflicts. A special emphasis has been placed upon identifying wounding patterns, adverse outcomes, and preventable deaths.[9,11,12,13,14] Improvements in body armor, military tactics, and the ability to respond quickly and effectively to trauma in a combat environment has led to dramatic improvements in morbidity and mortality.[1,13]

Lessons Learned - Know Your Environment

The following is an experience of a general surgeon during an early deployment:

> *I was assigned to a Forward Surgical Team (FST) that took us two hours driving south of Baghdad to reach by ground vehicle. It was my first time there; I was nervous about convoys, because we were driving through a heavily attacked route; and my intern classmate (a general surgeon) had been killed on an FST three weeks before I left for Iraq. Needless to say, my mind really wasn't on how far we were from the nearest Combat Support Hospital (CSH), what the evacuation times were, or even how far we were actually driving (we were going very slowly, stopping and starting a lot). So when we arrived at our FST site, it felt like we had come a long way to get there. On my prior FST experience in Afghanistan, our FST was two and one-half hours by fixed-wing aircraft to the nearest CSH.*
>
> *It turns out that we were only about 15 minutes by helicopter from the CSH. I assumed that we were much farther away. The proximity to more robust hospital support clearly makes a difference regarding how you triage multiple patients and what kind of operations you undertake. Nobody had oriented me to this, and at the time I didn't think to ask. I was at the FST 17 days before our first casualties arrived. There were four wounded casualties from an improvised explosive device (IED) attack. So here I am, three years out of residency, used to taking calls two to four times a month at a relatively slow Level II trauma center. I had performed maybe four or five blunt trauma-related operations in that period, and only a few penetrating trauma cases from Afghanistan. Now I had to simultaneously care for four wounded, multisystem trauma patients with one other surgeon, who was less than a year out of residency.*
>
> *We actually thought we did okay. One guy had an abdominal fragment wound but was stable and had a negative focused assessment with sonography in trauma (FAST). Two of the guys had extremity wounds and fractures, but were able to be splinted and were not hemorrhaging. One guy, however, had a systolic blood pressure (SBP) of 70 mm Hg, an inadequate improvised tourniquet on his leg, and open femur, tibial, and fibular fractures. He also had an injury to his distal superficial femoral artery. We spent some time getting proximal control in the groin, then dissecting out his artery through his huge, hematoma-laden, torn and distorted thigh, and putting in a temporary vascular shunt. We transfused him most of our blood bank of 20 units of red blood cells (RBCs). He was hemodynamically stabilized. He was cold, slightly acidemic, and coagulopathic when he left, but we had restored flow to his foot.*
>
> *Sorting out all these casualties took us maybe one and one-half hours. We finally got them on a helicopter and on their way about two hours after they arrived to us. When they arrived to the CSH, the patient with the vascular injury had clotted off his shunt. He went back to the operating room (OR) at the CSH and was revascularized, but had too much ischemia time and ended up losing his leg.*
>
> *When the trauma consultant to the Surgeon General came to visit us at the FST a few weeks later, he noted that it took him 17 minutes by slow-flying helicopter to get there from the CSH. As I reviewed the case with him, we realized that rather than a vascular shunt, which ended up being harder than it sounded and cost us a*

lot of blood products and time, we could have simply applied secure tourniquets to this guy, resuscitated him, and sent him on his way to the CSH. He would have reached a facility with vascular surgery support, robust blood bank and critical care services, and everything else he needed within an hour.

Dr. Alec Beekley, LTC
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Upon arriving at your area of deployment, get to know your CCC environment and resources. Rapid evacuation to a higher level of care may be the best contribution you provide to a casualty (Fig. 2). In some Combat Support Hospitals, specialists from trauma surgery, orthopedics, vascular surgery, ophthalmology, and critical care are available. Knowing the approximate evacuation time to a higher level of care may change critical decisions of whether to operate on a critically injured patient who will ultimately need transfer, or whether to transport immediately. What is the nearest Combat Support Hospital? How can transport be arranged? What is the fastest method of transport and expected transport time? How many critically-injured patients is your unit prepared to handle? If this number is exceeded, casualties who would otherwise stay for operative intervention may instead need to be transferred.

Know your CCC environment and recognize your resources and limitations.

The nature of war is that it is unpredictable. In civilian surgical practice, although the number and acuity of patients ebbs and flows, rarely is full capacity exceeded. In civilian urban settings, most injured patients are only 15 to 20 minutes from a Level I or II trauma center, and mass casualties are uncommon. In a combat environment, multiple-casualty-incidents are quite common (Fig. 3). The most common causes of injuries, explosions or exchanges of gunfire, are likely to create several casualties at once. Time to reach medical care may vary drastically not only by location, but by the tactical situation (i.e., ability to safely evacuate a casualty from a combat area without excessive endangerment of others).

Figure 2. *Level II FRSS-6/STP-7 in Southern Iraq in March, 2003.*

Figure 3. *Initial evaluation and resuscitation during a multiple-casualty-incident occurring at the Surgical Shock Trauma Platoon (SSTP) at Camp Taqaddum, Iraq 2006.*

Although Level III Combat Support Hospitals are well equipped with trauma specialists, blood banks, and multiple operating tables, many casualties first present to smaller, mobile medical and surgical units, such as Army Forward Surgical Teams (FSTs) or Marine Corps Forward Resuscitative Surgical System (FRSS) teams. Critical decisions on whether and when to intervene and when to transport critically ill casualties are made in these smaller mobile facilities (Table 1). These decisions will change with every new location, and even hour-by-hour with the availability of personnel, equipment, and transport. It is critical to know, to the best extent possible, what is occurring on the battlefield to prepare for the arrival of casualties. The chief surgeon or surgeon-of-the-day is usually the ultimate clinical decision maker and manages the clinical function of the unit and its resources. Attention to details, situational awareness of both internal and external conditions and good communication with the team are essential.

Service	Level II Facilities
Air Force	Mobile Field Surgical Team (MFST) Expeditionary Medical Support (EMEDS)
Army	Level II Medical Treatment Facility (MTF) Forward Surgical Team (FST)
Marine Corps	Forward Resuscitative Surgical System (FRSS)
Navy	Casualty Receiving and Treatment Ships (CRTS)

Table 1. *Level II treatment facilities with surgical capabilities according to military service branch. Adapted from Rasmussen, 2006.*[76]

All surgeons at forward surgical facilities need to have situational awareness that extends beyond taking care of patients in the operating room. The factors outlined in Table 2 are critical to optimal decision making.

Physicians in wartime are rarely fully prepared to treat combat-related injuries on their initial deployment. Explosive injuries comprise the majority of severe combat-related injuries (Fig. 4).[9,13] In peacetime, even experienced surgeons rarely encounter injuries from explosions. Explosions combine primary blast, blunt, and penetrating mechanisms to create multisystem, high-energy injuries with extensive soft-tissue damage, wound contamination, and hemorrhage from multiple sites. In addition to encountering unfamiliar injury patterns, newly deployed physicians must also learn a new medical system, with policies and logistics far different from the civilian sector. While standards of medical care remain the same, physicians are challenged to meet these standards in a new and often stressful environment.

> Physicians in wartime are rarely fully prepared to treat combat-related injuries on their initial deployment. Unfamiliar injury patterns, such as explosive injuries, and a new medical system with policies and logistics differing from the civilian sector contribute to a unique and often stressful environment. Rehearsing scenarios of care may prove beneficial to newly deployed careproviders.

Because time and circumstance may not afford a thorough orientation, it is critical to ask questions, learn from those with experience, and become familiar with available resources before the arrival of your first critically-injured patient. Care of the severely-injured combat casualty requires a team effort, and with

Figure 4. (Left) *US serviceman injured by a large mortar round explosion, with traumatic amputation of the right hand, near amputation of the left leg, and extensive soft-tissue wounds to the right leg. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.*

Figure 5. (Below) *FRSS patient care team at Forward Operating Base St. Michael outside Mahmudiyah, Iraq in March 2004.*

Forward Surgery - Lessons Learned

Triage Issues	**Situational Awareness**

• Triage Officer responsible for:
  • Clinical function of facility
    -Ultimate clinical decision maker
    -Status of all casualties
    -Consider tactical situation
  • Management of available resources
    -Personnel, supplies, ORs, blood bank
    -Control of walking blood bank
  • Initial triage of arriving casualty groups
  • Evacuation priorities
	• Internal
	  • Status personnel/supplies
	  • Number and physiologic status of casualties
	  • OR availability
	  • Blood products
	  • En-route-care capability
	• External
	  • Evacuation assets
	  • Time/distance to facility with resources to provide appropriate care
	  • Weather conditions
	  • Tactical situation

Table 2. *Forward Surgery - Lessons Learned.*

every team there is a learning curve. An important lesson learned from Forward Surgical Teams has been that teams need to rehearse scenarios of caring for multiple casualties before the first true casualties arrive (Fig. 5). This is extremely critical to improving the skills of corpsman, medics, and nurses unfamiliar with the care of critically-injured patients, and in improving the efficiency of physicians and the team. An open, critical, and nonjudgmental review after every major casualty incident, a "hot wash," has been found to improve the performance of Forward Surgical Teams.[15]

Joint Theater Trauma Registry (JTTR)

The civilian trauma systems and practice patterns in place today have emerged largely from the lessons learned during wartime. Military medicine has been the driving force behind many of the major advancements in trauma care. In the Civil War, the concept of a field hospital emerged, as did the link between treatment time and survival rates. In World War I, blood banks and the use of blood transfusions were developed. In World War II, antibiotics were put into widespread use, and the triage system was used to prioritize casualty evacuations.[16] The Korean War brought the development of Mobile Army Surgical Hospital (MASH) units, and with Vietnam, improvements were made in rapid evacuation systems with helicopters.[16,17]

Combat casualty care providers must use the lessons learned from wartime to improve subsequent patient care. The military medical system is capable of adopting new changes more quickly and efficiently than is the civilian sector, and the large number of severe injuries seen in a relatively short span of time allows for rapid evaluation of new innovations.

With the aim of improving CCC, the US Army established the Joint Theater Trauma System (JTTS) in 2004 to oversee the organization of medical facilities and resources as well as aeromedical evacuation systems.[18] Among its many roles, the JTTS has established the Joint Theater Trauma Registry (JTTR), an extensive database of every United States (US) combat casualty.[1] This comprehensive clinical database now contains over 40,000 entries.[19] The JTTR allows for retrospective analysis of the type and severity of combat injuries and the identification of potentially survivable injuries. It is the cornerstone by which performance improvement measures can be developed, implemented, and analyzed.

> With over 40,000 entries, the JTTR has allowed retrospective analysis and actionable research of combat injuries.

Data from medical charts, hospital records, transport records, and elsewhere are gathered, reviewed, and coded by a team of nurses and coders (Figs. 6 and 7). This allows for an unprecedented amount of medical data to be collected on US casualties. Important epidemiological questions, such as what is the rate of primary amputation or what is the percentage of thoracic injury with and without body armor, can now be answered. Moreover, the JTTR allows for analysis of changes that have been implemented, such as: are decreased transport times from the battlefield to medical aid associated with an improvement in survival, or does the rate of uncontrolled hemorrhage upon arrival to the hospital decrease with an increase in tourniquet use?

Figure 6. *An unprecedented amount of information is collected on US casualties allowing retrospective analysis and actionable research. Image courtesy of Defense Imagery Management Operations Center (DIMOC).*

PHYSICIAN TRAUMA ADMITTING RECORD (Theater Hospitalization Capability) - Previously Level 3

(All shaded areas mandatory for Joint Theater Trauma Registry data collection)

DATE: ______________________ **VITAL SIGNS**
TIME OF INJURY: ________________
TIME OF ARRIVAL: ____________ **T_____ P____ R___ BP __/___ O2 Sat ___**
LOCATION OF PRE-HOSP. CARE: ______________________________

TRIAGE CATEGORY
☐ Immediate ☐ Delayed
☐ Minimal ☐ Expectant

HISTORY & PHYSICAL

INJURY DESCRIPTION R L L R

(**AB**)rasion
(**AMP**)utation
(**AV**)ulsion
(**BL**)eeding
(**B**)urn %TBSA_____
(**C**)repitus
(**D**)eformity
(**DG**)Degloving
(**E**)cchymosis
(**FX**)Fracture
(**F**)oreign Body
(**GSW**)Gun Shot Wound
(**H**)ematoma
(**LAC**)eration
(**PW**)Puncture Wound
(**SS**)Seatbelt Sign

Pulses Present:
S= Strong
W= Weak
D= Doppler
A=Absent

HISTORY AND PRESENTING ILLNESS: ______________________________

MECHANISM OF INJURY

☐ Assault/Fight	☐ Helo Crash
☐ Biological	☐ Hot Obj/Liquid
☐ Blast/Explosion	☐ IED
☐ Blunt Trauma	☐ Knife/Edge
☐ Bomb	☐ Landmine
☐ Building Collapse	☐ Machinery
☐ Burn	☐ Mortar
☐ Chemical	☐ Multi-frag
☐ Crush	☐ MVC
☐ Drowning	☐ Plane Crash
☐ Fall	☐ Rad/Nuclear
☐ Flying Debris	☐ Single Frag
☐ Grenade	☐ UXO
☐ GSW/Bullet	☐ Other ________

CARE DONE PRIOR TO ARRIVAL
Pre-hospital Airway: ☐ no ☐ yes
Pre-hosp. Tourniquet : ☐ no ☐ yes Type: ____ TIME On:____ Off:______
Pre-hosp. Chest Tube: ☐ no ☐ yes R L (circle as applicable)
Temp Control Measure: ☐ no ☐ yes Type: ☐ body bag ☐ other
Intraosseous Access: ☐ no ☐ yes

HISTORY & PHYSICAL

Head & Neck: **Tymp Membranes**
Clear R ☐ L ☐
Blood R ☐ L ☐

Chest:

Abdomen:

Pelvis: ☐ Stable ☐ Unstable

Upper Extremities:

Lower extremities:

INITIAL PROCEDURES / DIAGNOSTICS
☐ C-Collar ☐ Intubate ☐ Canthotomy (circle L/R)
☐ Airway (oral/ nasal) ☐ CRIC ☐ Cantholysis (circle L/R)
☐ Chest tube ☐ R ☐ L ☐ Output ☐ Blood: mls ____ ☐ Air
☐ Needle decompression ☐ R ☐ L ☐ Output: ☐ Blood: mls ______ ☐ Air
☐ Pericardiocentesis ☐ Thoracotomy

Rectal Exam
Tone_____
Gross Blood +/-
Prostate_____
GYN______

☐ FAST
☐ DPL
☐ NG/OG
☐ Pelvic Binder
☐ Foley

☐ Closed Reduction ☐ EXT Fixation
☐ Splint ☐ Wound Washout
☐ Tourniquet Type CAT / SOFTT / Oth Time On:_____ Time Off:_____

☐ Closed reduction ☐ EXT Fixation
☐ Splint ☐ Wound washout
☐ Tourniquet Type CAT / SOFTT / Oth Time on:_____ Time off:_____

Neuro: GCS:______
E __/4 M __/6 V __/5
C-Spine Tender
☐ Yes ☐ No

Motor Deficit:
None
R UE/LE
L UE/LE

Skin: Burn: 1st 2nd 3rd %TBSA

Vision: Pupils R L
Brisk ☐ ☐
Sluggish ☐ ☐
NR ☐ ☐
Hand Motion ☐ ☐
Light Perception ☐ ☐
No Light Perception ☐ ☐
Size____mm ____mm

☐ Sedated
☐ Chemically Paralyzed
☐ Seizure Protocol
☐ Mannitol
☐ Intraosseus
☐ Central Line
☐ A-Line

HYPO / HYPERTHERMIA CONTROL MEASURES
Beginning Temp ______________ Time/date
Ending Temp ______________ Time/date
Temperature Control Procedure
☐ Bair Hugger ☐ Fwd Resus Fluid Warmer
☐ Chill Buster ☐ Body Bag
☐ Cooling Blanket ☐ Other ____________

LABORATORY

CBC **CHEMISTRY 7**

PT/ INR/ PTT
_____/_____/_______

LFT
Amylase: ______________________
Alk Phos: ______________________
LDH: ______________________
Bili: ______________________
SGOT: ______________________
SGPT: ______________________
Other:

URINALYSIS
SpGr: ________________
pH: ________________
Chem: ________________
Micro: ________________
RBC: ________________
WBC: ________________
Bact: ________________
HCG: ________________

ALLERGIES
☐ NKDA
☐ ASA
☐ PCN
☐ Sulfa
☐ Morphine
☐ Codeine
☐ Latex
☐ Other

ABG
FiO2: ______________ **VENT:**
pH: ______________ **YES NO**
pCO2: ______________ **ETT Size:** ____
pO2: ______________
HCO3: ______________
Sat: ______________
BE: ______________

MEDICATIONS
☐ DT
☐ Abx ______________
☐ Versed
☐ Morphine
☐ Fentanyl
☐ Other:

IV FLUIDS/BLOOD PRODUCTS
☐ Crystalloids __________cc's NS LR
☐ Colloids __________cc's
☐ PRBC's ________
☐ FFP ________ ____units
☐ Whole Bld ________ ____units
☐ Cryo ________ ____units
☐ PLT's ________ ____packs

PMH
☐ Unknown ☐ HTN
☐ None ☐ DM
☐ Cardiac ☐ Ulcer
☐ Respiratory ☐ Other
☐ Seizure

Patient NAME/ID:
Last: **First** **MI**
SSN/ID **DOB/AGE**

DATE: (dd,mm,yy)
MTF transferred from:

ASD(HA) September 2005 (March 2010 Interim Update) **This Form is Subject to the Privacy Act of 1974** **Page 1 of 2**

Figure 7. *Joint Theater Trauma Registry Treatment Record (front). Image courtesy of Joint Theater Trauma Systems Program, US Army Institute of Surgical Research.*

By understanding how deaths and injuries occur, investigators are best able to identify potential areas in which survival and other outcomes can be improved. Research by the JTTS and military healthcare providers remains ongoing, resulting in continued improvements in products, techniques, and systems-level aspects of medical care.

Combat Injury Patterns

Analysis of injury patterns and deaths during OEF and OIF indicates that most combat-related injuries occur as a result of injury from explosions, followed by gunshot wounds.[9,11] Only a small percentage of injuries are related to motor vehicle accidents and other causes. Injury patterns demonstrate that the highest rate of injury is to the extremities, followed by the abdomen, face, and head.[9,11] There is a low rate of thoracic injury, likely due to improvements in body armor.[9, 10,12]

Published data from the JTTR database from 2001 to 2005 demonstrated the following casualty data:[9]

- Mechanism of Injury – explosions (78 percent), gunshot wounds (18 percent)
- Injury Distribution – extremity (54 percent)
  abdomen (11 percent)
  face (10 percent)
  head (8 percent)
  thorax (6 percent)
  eyes (6 percent)
  neck (3 percent)
  ears (3 percent)

With extremity injury, there is a high frequency of penetrating soft-tissue injury and associated fractures due to explosive fragments and gunshots (Fig. 8). Accordingly, there is a much higher proportion of open fractures in combat casualties compared to civilian practice.[11,20]

Causes of Preventable Death

Analysis of JTTR statistics and data from prior conflicts has demonstrated that hemorrhage is by far the leading cause of potentially preventable combat-related death.[13,21] The case fatality rate has decreased significantly since Vietnam, from 16.5 percent to 8.8 percent.[1] The improvements in mortality are due not only to advancements in CCC, but improvements in body armor and rapid evacuation. A large part of the JTTS's mission is to analyze casualties, both wounded and killed, for the purpose of identifying, implementing, and evaluating potential improvements at any point in the medical system from first response to long-term care and rehabilitation.

Figure 8. *Fragmentation wound with near complete traumatic amputation of the right arm. The injury was nonsalvageable and required a completion amputation. Image courtesy of CDR Subrato Deb.*

Figure 9. *Injury caused by a rocket-propelled grenade (RPG) resulting in a large through-and-through wound to the left thigh and traumatic amputation of the lower right leg. Note the makeshift tourniquet applied in the field.*

Hemorrhage, much of which is considered compressible or amenable to tourniquet placement, is the leading cause of preventable combat-related death.

In Vietnam, casualties were described in the Wound Data and Munitions Effectiveness Team (WDMET) database.[22] From an analysis of the Vietnam casualties who ultimately died, but had survived until reaching medical care, a committee of surgeons deemed 8 to 17 percent of the deaths were potentially preventable with modern medical care.[21] The causes of these deaths included severe hemorrhage, burns, pulmonary edema, and sepsis. Furthermore, review of Vietnam data attributes over 2,500 deaths to extremity hemorrhage, which is potentially preventable (Fig. 9).

In the early years of the OEF and OIF (2001 to 2004), up to 15 percent of deaths were deemed potentially survivable. By far, the leading cause of these deaths was uncontrolled hemorrhage (82 percent), much of which was considered compressible or amenable to tourniquet placement.[13] Review of data has shown that over the past several wars (Korea, Vietnam, and the first Persian Gulf War), the killed in action (KIA) rate had not changed significantly.[23,24] The KIA rate refers to the percentage of casualties who die before reaching a medical facility out of all seriously injured casualties, and has been 20 to 25 percent since World War II.[24] In OEF and OIF, the KIA rate has decreased to 13.8 percent. Additionally, the case fatality rate, the percentage of severely wounded casualties who die, has decreased by half since Vietnam.[24] Of those KIA, the most common causes are severe head injury and severe thoracic trauma. However, 9 percent of those KIA die from hemorrhage from extremity wounds, 5 percent from tension pneumothorax, and 1 percent of airway obstruction. This group comprises most of the deaths considered potentially preventable (15 percent of those KIA) and has become the focus of many of the improvements in the medical system. Since many of these fatalities occur within the first couple of hours after injury, large efforts have been made to improve the early medical access and response.

Advances in Combat Casualty Care

Since the recognition of hemorrhage as the major cause of potentially preventable death, a tremendous effort has been made to improve hemorrhage control and treatment of other survivable injuries. Rapid evacuation, expanded training, improved equipment, and a change in resuscitative and surgical techniques are some of the approaches discussed in greater detail below and in the chapters that follow.

Advancements in Combat Casualty Care Training

The golden hour and its associated platinum ten minutes of trauma response lies in the hands of first responders. On the battlefield, this is often another soldier, a combat lifesaver, or combat medic. In World War II, Vietnam, and OEF and OIF, the vast majority of combat deaths occur before the casualty reaches a medical facility.[24]

Most medics, physicians and other medical personnel, and all Special Operations Forces (SOF) personnel undergo a Tactical Combat Casualty Care (TCCC) training course. The TCCC course was developed to teach deployed careproviders key elements of lifesaving prehospital medical care.[25] Among the core curriculum, techniques in hemorrhage control, needle thoracostomy, casualty positioning, and even on-site cricothyroidotomy are taught.[25] Tactical Combat Casualty Care was begun by the Naval Special Warfare Command in 1993 and later continued by the US Special Operations Command (USSOCOM). Much of its development came from a 1996 study outlining guidelines for combat care for Special Operations corpsmen and has since been expanded to all branches.[25]

Figure 10. *US soldiers run for cover after a simulated bomb explosion during a casualty evacuation exercise in the mock village of Medina Wasl at the National Training Center (NTC), Fort Irwin, California. Image courtesy of Defense Imagery Management Operations Center (DIMOC).*

Injury care will often need to be delivered while an area is still under hostile fire, delaying the initial arrival of medical personnel and equipment (Fig. 10). Prior to evacuation, available patient care equipment is limited to what can be carried by the first responder. Equipment such as stethoscopes and blood pressure cuffs are not available, and would not often be useful in a noisy environment. First responders must rely on basic visual and physical examination findings to dictate treatment. Casualty evacuation times are widely variable, ranging from minutes to hours, depending on the tactical situation and resources.

Given these constraints, TCCC training was designed to incorporate several principles that may depart from the standard approach to civilian trauma. These include:

- Cardiopulmonary resuscitation (CPR) is not attempted for a casualty with no signs of life
- Airway management and cervical spine immobilization are delayed until the casualty and rescuer are both removed from hostile fire
- Casualties found unconscious, but breathing, are given a nasopharyngeal airway and placed in the recovery position
- Only the minimal amount of clothing is removed to identify and treat injuries to minimize hypothermia
- Control of bleeding is paramount and takes precedence over all other efforts, including obtaining intravenous access and extrication from vehicles
- Early use of a tourniquet and hemostatic dressings are encouraged in the setting of hemorrhage
- Intravenous access is not attempted for casualties with superficial wounds, a strong radial pulse, and a normal Glasgow Coma Scale (GCS) motor score

Figure 11. *US soldiers from Charlie Company, 4th Battalion, 23th Infantry Regiment conduct a foot patrol in the Helmand province of Afghanistan in January, 2010. Image courtesy of Defense Imagery Management Operations Center (DIMOC).*

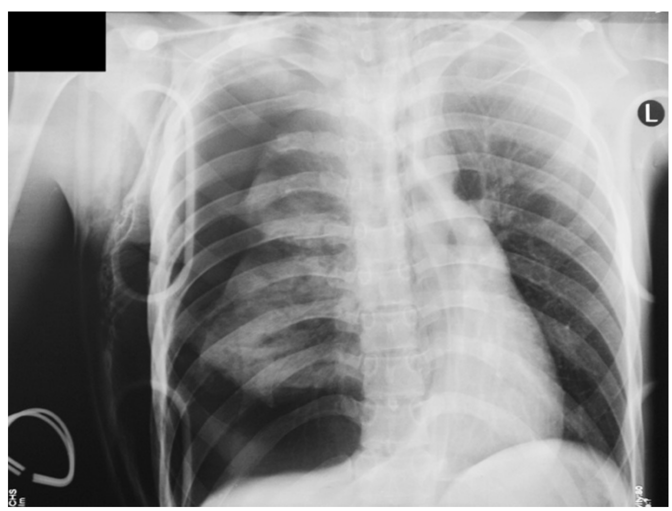


Figure 12. *Tension pneumothorax, a cause of potentially preventable battlefield death, may be treated by needle decompression.*

Equipment Changes

Body Armor

Expansion in the use of body armor, improvements in its surface area coverage, and enhancement of the armor's ability to deflect high-velocity projectiles are believed to explain the lower overall incidence of thoracic injury during OEF and OIF (Fig. 11).[1,9] Early studies also suggest body armor decreases the incidence of abdominal injuries.[10,26,27] Technological improvements in body armor are believed to contribute to the improvement in survival seen since Vietnam. Body armor came into widespread use during Operation Desert Storm, and its use further expanded during the current conflicts. In Vietnam, the rate of thoracic injury was 13 percent, in OEF and OIF, this rate has decreased to 5 percent.[9] Moreover, an analysis of casualties in 2004 demonstrated a rate of thoracic injury of 18 percent in those without body armor, and less than 5 percent in those wearing armor.[1] Despite the decrease in thoracic injuries, tension pneumothorax has been recognized as a potentially preventable cause of battlefield death (Fig. 12).[13,21] This resulted in the training of most SOF in the technique of needle thoracostomy. First responders now carry a large-bore needle as part of their battlefield equipment.

Hemorrhage Control Adjuncts

Tourniquets, rarely used in the civilian sector, have become a standard part of every soldier's equipment, and all medics and SOF personnel have been trained in their use (Fig. 13). In the past, tourniquets were avoided due to concerns regarding their misuse leading to limb ischemia and lack of adequate hemorrhage control. However, this scenario typically was associated with makeshift tourniquets, such as a bandage and a stick, which were often improperly applied.

Figure 13. (Above) *The Combat Application Tourniquet®. Liberal use is recommended for uncontrolled extremity hemorrhage in the tactical environment. Image courtesy of North American Rescue, LLC.*

Figure 14. (Right) *A casualty arrives at the SSTP at Camp Taqaddum, with Combat Application Tourniquets in place. Image courtesy of CDR Subrato Deb.*

Tourniquets save lives. Improved survival is associated with tourniquet placement before the onset of shock, while timely removal avoids complications.

Newly designed tourniquets combined with improved widespread training on tourniquet use have played a major role in improving hemorrhage control following combat injury.[28] This is especially true in battlefield or other austere environments, when access to definitive care may be delayed. At the start of OEF and OIF, there was very little tourniquet use. However, tourniquets are now applied following nearly every severe extremity injury (Fig. 14).[29] A 2008 study of severe extremity injury in an OIF Combat Support Hospital deemed that tourniquets are effective in controlling hemorrhage with no increased incidence of significant limb ischemia or early adverse outcomes.[29] Kragh et al. conducted the first prospective study of 2,838 casualties with major limb trauma admitted to a Level III Combat Support Hospital in Baghdad, and demonstrated survival benefit associated with tourniquet use.[28] Improved survival was also associated with placement of tourniquets prior to the onset of clinical signs of shock. Of the 232 patients who received 428 tourniquets (applied to 309 injured limbs), transient nerve palsy was the only adverse outcome attributed to their use.[28,30] If removed within six hours of application, tourniquets save lives without causing limb damage or secondary amputation.

Topical hemostatic agents may be used as adjuncts in the treatment of noncompressible hemorrhage.

Figure 15. *QuikClot® applied to a large penetrating fragmentation wound of the left shoulder.*

Hemostatic, clot-promoting agents, such as Combat Gauze™, WoundStat™ granules, Celox™ powder, QuikClot® and HemCon™ dressings, have been used for bleeding not immediately controllable with direct pressure, pressure points, or tourniquet use (Fig. 15).[31,32,33] These hemostatic agents were developed for use in conjunction with the standard techniques of hemorrhage control, including direct pressure, elevation, and pressure point use. Some form of hemostatic dressing is now given to every individual in a combat zone. Animal models and early studies from OEF and OIF demonstrate the superiority of many of these dressings over standard gauze dressings and describe safety considerations surrounding their use.[31,32,33] A more detailed discussion of combat dressings is provided in the Damage Control Resuscitation chapter.

Organizational Innovations

Beyond new products and techniques, there has been improvement in the trauma and evacuation systems at organizational levels. Since 2003, the trauma system has been organized into levels of care designed to minimize the time from injury to treatment, and to provide a continuum of care. Forward Surgical Teams are small, mobile units capable of performing a limited number of lifesaving surgeries. These FSTs have been organized into rapidly responsive and efficient units. The process of casualty evacuation from the battlefield, to the initial level of surgical care, and then on to definitive care facilities in Germany and the United States, has dramatically improved in speed and capability. These rapid evacuation systems have enabled casualties to reach forward medical facilities in minutes rather than hours. The military is now able to transfer ventilated, critically ill patients from forward surgical sites near point-of-injury, over distances of thousands of miles while providing state-of-the-art critical care en-route (Fig. 16).

Figure 16. *An en-route-care nurse helps package a critically-injured casualty for transport in the operating room at Camp Taqaddum, Iraq.*

Echelons of Care

To meet wartime needs, CCC and evacuation are organized by echelons of care. In this context, the word echelon refers to level of command and control. The medical care delivered at each echelon of the battlefield corresponds with respective levels of care (e.g., Level II care is delivered in Echelon II) (Fig. 17).

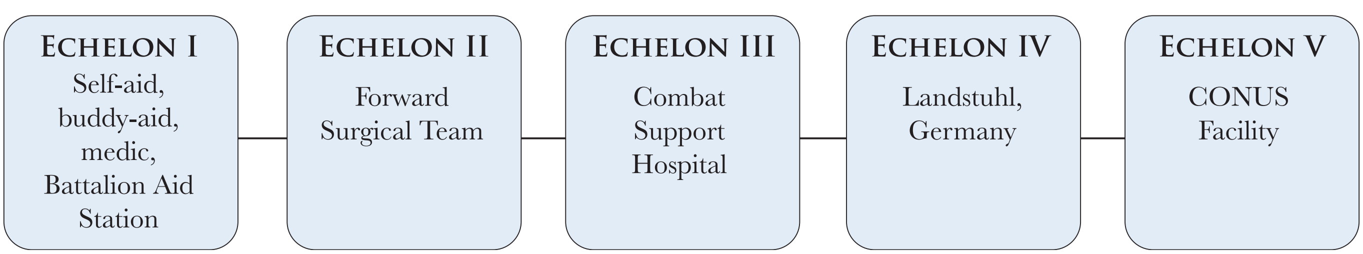


Figure 17. *Evacuation chain for combat casualties.*

Trauma system activation in OEF and OIF occurs well before the combat casualty reaches the hospital. On the battlefield, the first medical responder to a casualty is usually another soldier or a combat medic, who in some instances will rapidly move the patient to a Battalion Aid Station. Care provided by the first responder through the Battalion Aid Station is considered Level I. The first response may occur when still under fire or in dangerous circumstances, and only limited equipment may be available. The combat medic assesses whether the casualty will require immediate evacuation and responds to immediately life-threatening injuries (Fig. 18). Most commonly, this includes control of hemorrhage using tourniquets as first-line therapy if care is being delivered under fire. Once the casualty and first responder are no longer under fire, hemorrhage control may be reassessed. Depending on the findings upon reassessment, hemorrhage control may either be augmented with additional tourniquets or hemostatic dressings, or controlled with a less stringent method (e.g., pressure dressing).

Figure 18. *Combat medics evacuate a wounded casualty on a Black Hawk helicopter. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.*

Rapid evacuation systems have enabled combat casualties to reach forward medical facilities in minutes rather than hours. For patients requiring evacuation, the goal is to reach surgical care within one hour of injury.

For patients requiring evacuation, the goal is to reach surgical care within one hour of injury. Depending on the location, the casualty may initially reach either a Level II or Level III facility. Transport from point-of-injury or a Level I facility to a Level II or III facility is termed casualty evacuation (CASEVAC). A Level II facility is typically made up of a FST, capable of providing immediate, life-sustaining resuscitation and surgery until the patient can reach a higher-level facility for definitive treatment and longer-term care. Most FSTs consist of five to 20 personnel, including at least three surgeons, an orthopaedic surgeon, nurse anesthetists, critical care nurses, and technicians.[34] Forward Surgical Team personnel are capable of rapid assembly and takedown of the facility. The facility comprises two operating tables and a blood bank supplying 20 to 50 units of packed RBCs. Most FST facilities now carry plasma and recombinant factor VIIa. These FST facilities logistically support up to 30 operations before needing to resupply. The FST facilities typically do not have plain radiography capacity, but most have portable ultrasound machines.

Physicians should become proficient in the use of ultrasound for the evaluation of a combat casualty.

Forward surgical units offer a highly effective combination of proximity and capability for patients who cannot be evacuated rapidly to a Combat Surgical Hospital. Determining the ideal relationship between proximity to surgical care and the capability of the surgical unit, however, remains a challenge. In many cases, the tactical situation has permitted rapid helicopter casualty evacuation directly to a Level III facility, approaching that of transporting a civilian trauma patient to a regional Level-one trauma center in the United States. Inclement weather, the inability to land a casualty evacuation helicopter close to an active firefight, or a high volume of casualties arriving at the closest Level III facility may preclude this practice in theater. Similarly, remote combat operations may not allow timely transport of a surgical patient to a Combat Support Hospital. In these situations, the forward surgical unit's mobility and sophisticated capabilities provide valuable resources.

The physical and logistical resources required to provide life and limb-salvaging care to severely injured casualties are considerable. Managing several combat casualties over a relatively short timeframe (24 hours) can completely overwhelm a unit. The logistical support, communications, security, and ability to transfer postoperative patients are as essential to the success of these units as is their forward location. Thoughtful consideration of the tactical solution is needed to balance the benefits of enhanced proximity afforded by small and mobile forward surgical units against the disadvantages of dispersing resources and experience throughout the battlespace. Dispersion of small surgical units across the combat theater without including them in an integrated trauma system will not be effective. As noted by Dr. Ogilvie in commenting on the success of the Forward Surgical Teams used by the British 8th Army fighting the German Afrika Corps in the North African desert during World War II, "This point must be insisted on, because there is constant temptation on the part of keen medical administrative officers to push forward their surgeons beyond the point where they can do useful work, and for surgeons there to undertake more than lifesaving surgery with the splendid folly that prompted the charge of the Light Brigade."[35]

Level III facilities include Combat Support Hospitals and are significantly larger, semi-permanent hospitals capable of providing immediate patient resuscitation, temporizing and definitive surgeries, medium-term intensive care unit (ICU), and postoperative care for hundreds of patients.[1] At this level, surgical specialties including orthopedics, neurosurgery, maxillofacial surgery, urology and ophthalmology are available. All have plain radiography and fluoroscopy, and some have computed tomography (CT) capability. Level III facilities often treat host nation casualties in addition to military casualties (Fig. 19). As of 2005, there were three Army-based Combat Support Hospitals in Iraq and one in Afghanistan, as well as one Air Force Theater Hospital in Iraq. Most have five to 10 trauma bays, two to five operating rooms, and about 10 to 20 ICU beds (Fig. 20).

United States casualties requiring longer-term care are then evacuated to a Level IV facility. Nearly all US casualties in Iraq and Afghanistan are evacuated to Landstuhl Regional Medical Center in Germany, a large hospital offering all surgical specialties and rehabilitation. Finally, US casualties not expected to return to duty are ultimately evacuated back to the Continental United States (CONUS) to a Level V facility. These include Brooke Army Medical Center, Walter Reed Army Medical Center, National Naval Medical Center Bethesda, and almost all of the tri-service major medical centers.

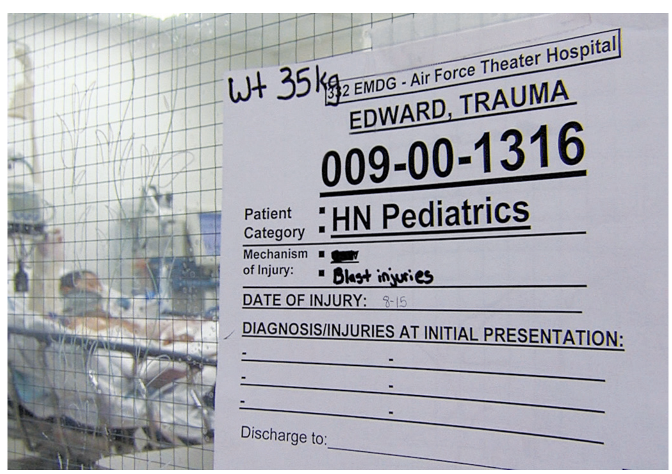


Figure 19. *Outside the room of a 14-year-old host national patient who sustained blast-related injuries and was treated at a Level III facility in Balad AB, Iraq.*

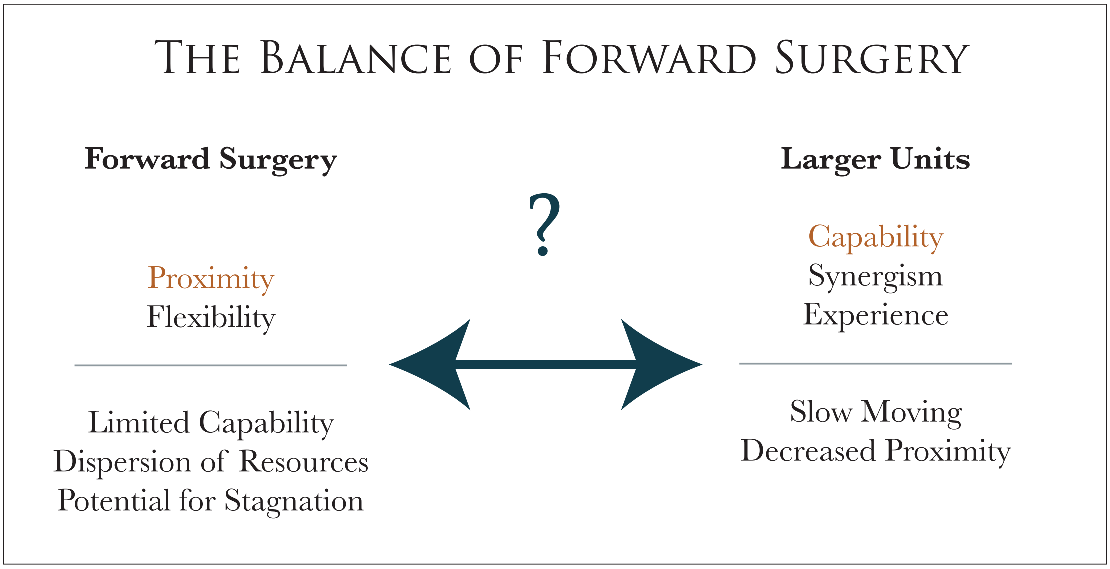


Figure 20. *Important considerations in casualty evacuation (CASEVAC). The prime objective is to stabilize and transport the wounded from the battlefield to the nearest appropriate medical facility available, in the most expedient fashion.*

Patient Evacuation and Transport

"The stated vision of the JTTS was to ensure that every soldier, marine, sailor, or airman injured on the battlefield has the optimal chance for survival and maximal potential for functional recovery. In other words, to get the right patient to the right place at the right time."[1] The rapid and efficient evacuation of a large number of casualties, including those with critical injuries, has been one of the major advances in OEF and OIF. Most severely injured casualties can be rapidly transported from the field by helicopter via casualty evacuation (CASEVAC), or between Level II and Level III care facilities as a medical evacuation (MEDEVAC) (Fig. 21). The CASEVAC system is designed for speed over medical capability. The helicopter may not contain medical equipment and the crew may have little or no medical training. Medical evacuation crews have medical training and fly in designated helicopters with some medical equipment.[36] Helicopters are equipped with both a flight crew and medical team, and critically ill casualties are accompanied by an

Figure 21. *A pair of Army Black Hawk helicopters take off from Balad AB to perform a MEDEVAC. The MEDEVAC crews are a critical link in the chain of events to ensure casualties in Iraq are transported to the next level of care within one hour of being injured. Image courtesy of Defense Imagery Management Operations Center (DIMOC).*

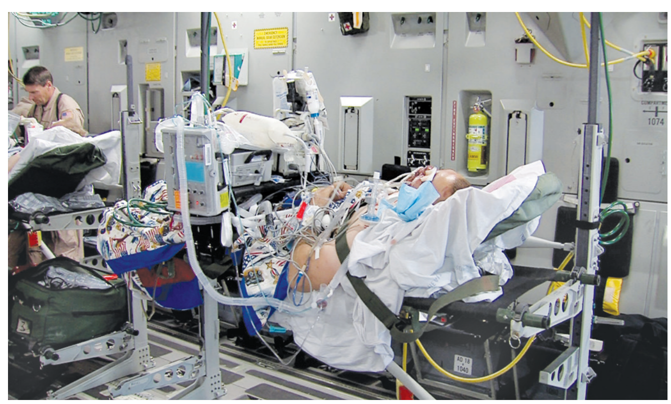


Figure 22. *USAF Critical Care Air Transport Teams (CCATTs) have enabled the movement of critically ill patients, even in the midst of ongoing resuscitation.*

en-route-care nurse who manages the patient during transport from Level I or II to Level III. Casualties are transported from the battlefield to the nearest medical facility (usually a Level II facility) either by ground transport or helicopter. Distance, weather, ground conditions, availability, number of casualties and severity of injury are among the factors used to determine which mode of transport will be used.[37]

The US Marine Corps utilizes en-route-care (critical care nurses) to provide ongoing management of ventilated, critically ill patients during transport from a forward unit to Level III care. These nurses belong to the forward unit and are not part of the air transport unit. After completion of transfer to Level III facilities they return to their originating unit. En-route nursing care is an indispensable link as patients move from Level I through Level III facilities. During the three busiest periods of First Marine Expeditionary Force (I MEF) Operations in Iraq (2003, 2004, and 2006) more than 600 en-route-care missions, moving 675 patients, were flown from Level II to Level III facilities. This accounted for 16 percent of all combat casualties during that time. Virtually all (99.5 percent) of the patients arrived safely at Level III. There were four patients who arrived unstable and all had severe injuries. All four were nonpreventable deaths on review (unpublished data, USMC 2008). Unfortunately, this was not always the case for patients transported without nursing care. Although further refinements and increased training for en-route-care between Level II and III units are necessary, this practice is an important step forward in CCC.

An aeromedical evacuation system was developed during OEF and OIF for long-range transportation. This system has transported thousands of casualties by fixed-wing aircraft since its inception.[38] In Vietnam, transporting an injured casualty back to the United States typically took well over a month. With the advancements in aeromedical transport in OEF and OIF, most casualties reach Germany or the United States within 36 hours of injury.[4,36,38] This rapid transfer of care carries the risk of losing key information along the way. Communication between the transport team and receiving careproviders is critically important during such transfers. The medical capabilities of aeromedical aircraft and personnel have significantly advanced, and these aircraft function as a 'mobile ICU' (Fig. 22).

With advancements in aeromedical transport during OEF and OIF, most casualties reach Germany or the United States within 36 hours of injury.

Transport of the most critically ill patients is conducted by Critical Care Air Transport Teams (CCATTs). Each CCATT is staffed with at least one physician and two critical care nurses, with the capability to transport critically ill ventilated patients for eight to 12 hours at a time, to a higher level of care. The CCATTs were developed in 1994 by the US Air Force and allow for postoperative transport of patients to Level IV and V hospitals where continuing intensive care, secondary operations, and rehabilitation can occur. Evacuation out of theater to Level IV and V facilities is termed air evacuation (AIREVAC). This enables Combat Support Hospitals in Iraq and Afghanistan to preserve their ICU and surgical resources.

Since casualties with injuries not allowing them to return to duty will rapidly move through the system and rarely spend significant time at any specific level of care, communication of key information concerning their injuries and treatment is essential for optimal care. This is most problematic in an immature theater where communications and bandwidth are limited. Under these circumstances, multiple methods of transferring information have been utilized. These include paper records, writing on patients or dressings, and direct verbal transfer by accompanying medical personnel (Fig. 23). Additionally, items such as handheld portable dictaphones and even memory sticks with downloaded photos of injuries and paper records have been tried with varying success. In a mature theater with established communication capability, availability of the Joint Patient Tracking Application (JPTA) – a web-based application that allows users to obtain real-time information, e-mail, and direct phone communication – have simplified transferring medical information and providing feedback to forward units on outcomes.[1]

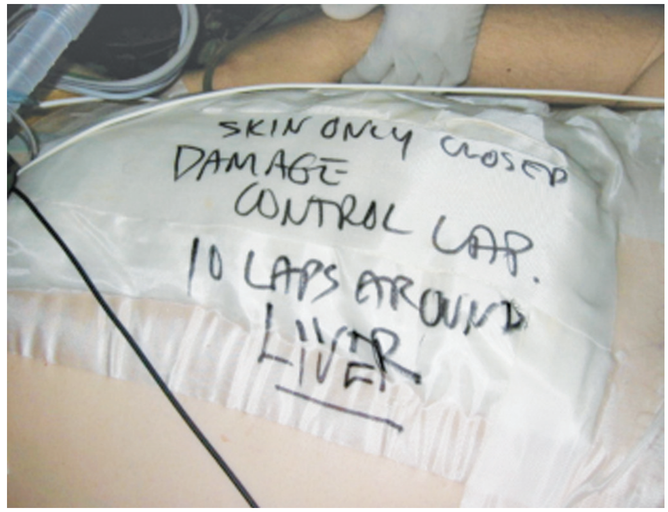


Figure 23. *Improvised patient information communication strategy. Patient information is written directly onto the dressing of a patient emerging from a damage control laparotomy. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.*

Damage Control Strategies

Beyond new products and training, there has been a significant change in the management of critically injured patients reaching a medical facility, termed damage control resuscitation (DCR). Damage control resuscitation emphasizes resuscitation with hemostatic blood products and focuses on rapid control of bleeding and immediately life-threatening injuries. Its counterpart, damage control surgery (DCS) focuses only on immediately critical surgical interventions and delays more definitive care of injuries until the patient can be stabilized. In conjunction, these practices aim to prevent the lethal triad of acidosis, hypothermia, and coagulopathy.

Damage Control Resuscitation

The recognition of hemorrhage as the primary cause of preventable combat death led to significant changes in the initial resuscitation of severely injured patients.[13,21] Most death due to hemorrhage occurs within six to 24 hours of injury. This makes hemorrhage control, reversing coagulopathy, and restoring tissue perfusion critical. Advanced Trauma and Life Support (ATLS) curriculum recommends aggressive resuscitation with crystalloids both in the prehospital and hospital settings.[39] Moreover, when a massive transfusion is required, conventional practice involves transfusion of packed RBCs first, with addition of platelets and clotting factors only after the transfusion of a full blood volume (e.g., five liters).[39]

Conventional resuscitation practices have been significantly influenced by recent CCC experiences in OEF and OIF. Upon arriving at a hospital setting, many severely injured casualties are already coagulopathic. One-third or more of combat casualties present with an international normalized ratio (INR) of 1.5 or greater.[40] Aggressive resuscitation with crystalloid and packed red cells worsens coagulopathy through dilution, promotion of hypothermia, and worsening of acidosis.[40] This lethal triad of acidosis, hypothermia, and coagulopathy has a downward spiral effect characterized by acidosis and hypothermia worsening coagulopathy, leading to progressive hemorrhaging, which itself worsens all three conditions (Fig. 24). Each of the three conditions has been shown to be an independent predictor of mortality in severely injured casualties.[40]

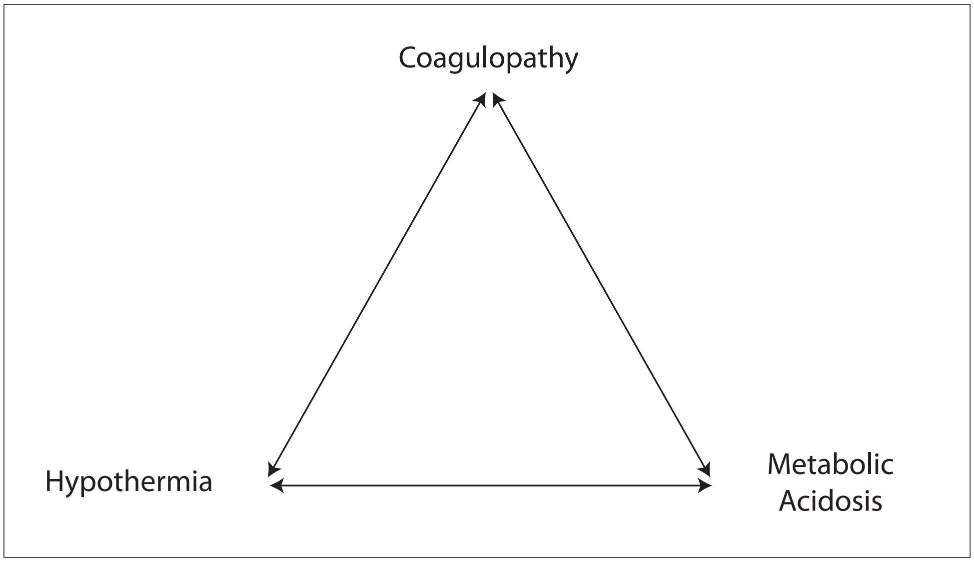


Figure 24. *The lethal triad of acidosis, hypothermia, and coagulopathy. Acidosis and hypothermia worsen coagulopathy, leading to progressive hemorrhage and worsening of all three arms of the triad.*

With conventional resuscitation practices, aggressive resuscitation with crystalloid solutions worsens coagulopathy through hemodilution, promotion of hypothermia, and worsening of acidosis. In contrast, DCR emphasizes resuscitation with hemostatic blood products, rapid control of bleeding and immediately life-threatening injuries, prevention of hypothermia, permissive hypotension, and minimal use of crystalloids.

Typical crystalloid fluids, including 0.9% normal saline and lactated Ringer's solution, have a pH of 5.5 and 6.6, respectively.[41] They are often infused in large quantities through large peripheral intravenous catheters in prehospital and early resuscitative settings. These crystalloid fluids cause a lowering of blood pH and a dilutional effect on the platelets and clotting factors needed to control bleeding. Despite attempts at warming these crystalloid fluids prior to infusion, they are rarely administered at body temperature and frequently contribute to patient hypothermia. Prolonged transport times between initial injury and arrival to medical care further potentiate the risk for hypothermia in combat casualties. Acidosis results primarily from production of lactate and other metabolic byproducts due to anaerobic metabolism, a result of inadequate tissue perfusion during patient shock. While crystalloids lower pH, massive transfusion of blood products is thought to promote acidemia as well.[42] Stored RBCs are thought to have a pH of 7.15 or lower.[43] Transfusion of large quantities of stored RBCs may have a profound lowering effect on body pH.

The goal of DCR is to reverse the three components of the lethal triad and rapidly control hemorrhage. Damage control resuscitation applies to both initial resuscitative efforts as well as the first 24 to 48 hours of postoperative ICU care. Novel aspects of DCR include permissive hypotension, minimal use of crystalloids, rapid transfusion of blood products in an RBC-to-plasma-to-platelet ratio of 1:1:1, aggressive prevention of hypothermia with warm blankets and fluids, use of fresh whole blood (FWB) when available, and the use of new products, including hemostatic agents and recombinant factor VIIa, when appropriate for severe hemorrhage.[44]

An important aspect of DCR is early recognition of critically ill combat casualties who will require massive transfusion and are susceptible to the aforementioned issues surrounding resuscitation. Limited blood product availability, lab capability, and personnel at forward resuscitative or surgical sites create the need for judicious utilization of resources. The rapid and precise recognition of casualties requiring DCR has been aided by injury pattern recognition. Casualties who present with any of the injury patterns shown in Table 3 are likely to need massive transfusion and should be treated by DCR techniques.

Rapid Recognition Of Casualties Requiring DCR By Injury Pattern
• Truncal, axillary, neck, or groin bleeding not controlled by tourniquets or hemostatic dressings • Major proximal traumatic amputations or mangled extremity • Multiple long-bone or pelvic fractures • Large soft-tissue injuries with uncontrolled bleeding • Large hemothorax (greater than 1,000 milliliters) • Large hemoperitoneum

Table 3. *Injury patterns as predictors of massive transfusion.*

Permissive Hypotension

Trauma patients suffering from severe injury, such as limb amputation, often arrive at medical care facilities with minimal bleeding. Once resuscitation is initiated, patients start rebleeding, often uncontrollably. Since rate of hemorrhage has a direct relationship with mean arterial pressure, it is postulated that lower blood pressures may slow the rate of hemorrhage, allow for clotting to occur, and help preserve blood volume.[44] Thus, some degree of hypotension may be protective in preventing further hemorrhage in critically injured patients. This must be weighed against the effect of hypotension on end-organ perfusion leading to multiple organ dysfunction syndrome (MODS).[45]

Traditional ATLS teaching calls for two large-bore intravenous catheter insertions in the prehospital setting with immediate aggressive crystalloid replacement.[39] However, numerous animal-model studies suggest that this leads to poorer outcomes in both blunt and penetrating trauma, perhaps due to interference with normal physiologic responses to hemorrhage.[46,47,48] In combat settings, casualties now receive minimal crystalloid or blood products in the field. Combat medics practice permissive hypotension, allowing for a mild degree of hypotension (systolic blood pressure of 90 mm Hg) in patients with a normal mental status.[49,50] In the field, this translates to a palpable radial pulse in an alert patient. The goal is to prevent the conversion of controlled hemorrhagic shock to uncontrolled hemorrhagic shock in severely injured casualties before reaching definitive care.

In a combat setting, patients without evidence of head injury who exhibit a normal mental status and a palpable radial pulse should not receive intravenous fluids.

Blood Product Transfusion Ratios

Although the definition of massive transfusion varies, the term is commonly applied to a transfusion of 10 units of RBCs or greater within a 24-hour period (Figs. 25 and 26).[51] Most combat and civilian casualties do

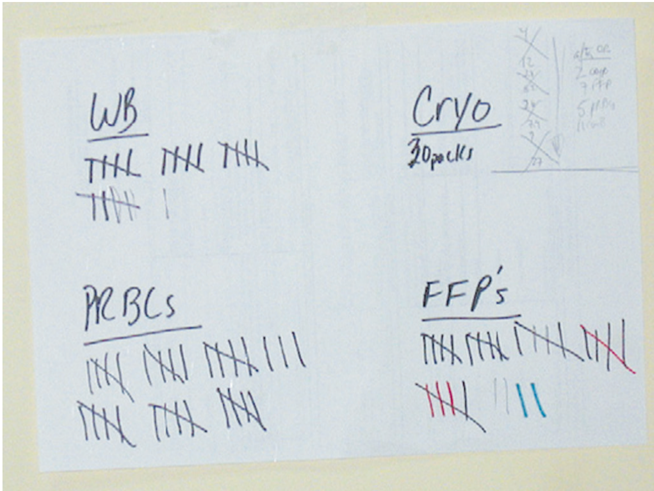


Figure 25. *Running tally of blood products administered, posted on the wall above a casualty's bed. The casualty sustained injuries from multiple transabdominal gunshot wounds.*

Figure 26. *The need for massive transfusion should be determined early. Approximately 8 percent of combat casualties require massive transfusion. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.*

not require massive transfusion. In the civilian setting, it is required in only 1 to 3 percent of trauma cases. In a combat setting, the frequency is higher due to the increased incidence of penetrating trauma and blast injury. In OIF, the rate is 8 percent, compared with up to 16 percent during Vietnam.[52]

In a combat setting, the frequency of massive transfusion is higher due to the increased incidence of penetrating trauma and blast injury.

The aim of RBC transfusion is to restore the oxygen-carrying capacity of the blood, replace lost volume, and restore tissue perfusion. For patients requiring several units of RBCs, conventional teaching was that replacement of platelets and clotting factors due to dilution was not required until the patient had been transfused a full blood volume. Thus, most massive transfusions have been heavily weighted towards RBC transfusion before other blood products were added, resulting in low plasma-to-RBC and platelet-to-RBC ratios. Multiple retrospective studies of both civilian and combat trauma patients have shown an increase in mortality, particularly in death due to hemorrhage, associated with low plasma-to-RBC and platelet-to-RBC ratios.[53,54,55] In a 2008 study by Holcomb et al., a review of 466 civilian patients requiring massive transfusion demonstrated that patients receiving higher amounts of plasma and platelet transfusion in the context of massive transfusion had decreased truncal hemorrhage. This subset of patients also had increased six-hour, 24-hour, and 30-day survival, had less ICU and ventilator days, and spent fewer days in the hospital.[55]

Blood product transfusion studies following combat-related injuries have shown the same trends. A 2008 study by Spinella et al. reviewed 708 patients in Combat Support Hospitals who required at least one unit of RBC transfusion. Each unit of RBCs transfused was associated with increased mortality, while each unit of plasma transfused was associated with increased survival.[56] Similarly, a 2007 study by Borgman et al. reviewed 246 patients at Combat Support Hospitals requiring massive transfusions and divided them into three groups based on the ratio of plasma-to-RBCs received. The three groups had the same median injury severity score of 18. The group with the lowest ratio (median 1 plasma: 8 RBC units) had significantly higher overall mortality (65 percent) and death due to hemorrhage (92.5 percent) compared to the high ratio group (median 1 plasma: 1.4 RBC units), which had a 19 percent mortality and 37 percent rate of death due to hemorrhage.[53]

Such studies have led to a paradigm shift in the provision of massive blood transfusion in combat casualties, with a low-ratio goal approaching 1:1:1 for RBCs, plasma, and platelets. This has led to significant changes in blood banking practices. For instance, since plasma is frozen, Combat Support Hospitals now pre-thaw fresh frozen plasma (FFP) daily to ensure rapid availability.

Role of Fresh Whole Blood

With the advent of a low-ratio goal (e.g., 1:1:1) for massive blood product transfusion in combat casualties, the ideal blood replacement in the context of hemorrhage may be whole blood, rather than component transfusion.[57,58,59] Whole blood contains the most physiologic ratio of red cells, platelets, clotting factors, and fibrinogen. Secondarily, one unit of whole blood contains overall less volume than the equivalent in blood components, which can be important in patients receiving massive transfusion who are at high risk of third-spacing fluids and developing pulmonary edema. A retrospective study of 354 patients with traumatic hemorrhagic shock receiving blood transfusion found both one-day and 30-day survivals were higher in the fresh whole blood cohort as compared to the component therapy group.[57]

In addition to the problems associated with dilutional effects when RBCs alone are transfused, the age of stored RBCs is also associated with an increase in mortality.[60] The average lifespan of an RBC is 120 days, and this is traditionally the maximum storage time for a unit of frozen RBCs. As red cells age, an increasing number of cells will die or become damaged and release intracellular products. In animal models, transfusion of stored RBCs has been shown to cause release of inflammatory mediators and result in higher infection rates.[61] In addition, as red cells age, their oxygen-carrying capacity per unit diminishes and the restoration of tissue perfusion decreases, which may have adverse clinical effects.[62]

Recent investigation has given significant attention to the use of warm fresh whole blood (FWB) for massive transfusion required in a combat setting. The use of FWB started during World War I, initially out of necessity due to limited supplies of blood components in combat hospital settings. Transfusion practices have been revised during OEF and OIF to increase the safety and efficiency of the process.[44] When the number and severity of casualties exceeded the ability of blood banks to keep up with transfusion requirements, walking blood banks were established to rapidly increase the supply of available blood in disaster scenarios (Fig. 27). Whole blood donated by military personnel, prescreened and blood-typed, can be rapidly cross-matched and available for use within hours without being divided into components. Though initially developed out of necessity, the use of warm FWB is now under investigation as a potentially superior approach compared to component therapy for massive transfusion.[57,63]

Figure 27. *Military personnel donate blood at the Walking Blood Bank, Camp Taqaddum, Iraq in 2006.*

Whole blood donated by military personnel, prescreened and blood-typed, can be rapidly cross-matched and available for use within hours without being divided into components.

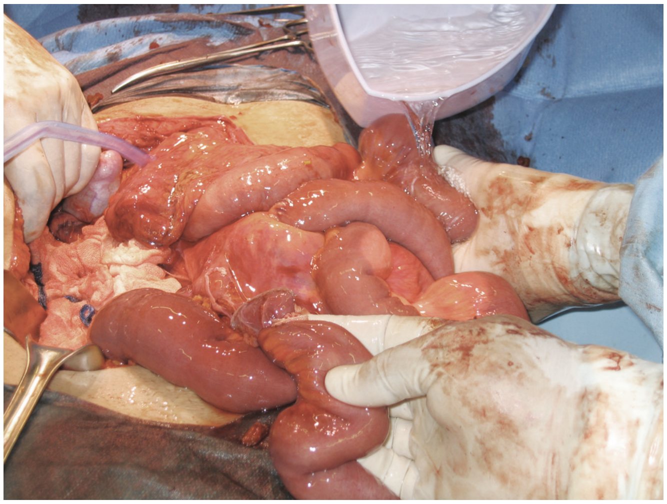
Role of Recombinant Factor VIIa

Recombinant factor VIIa has been under study for its use in severe hemorrhage.[64,65] Currently, recombinant factor VIIa (rFVIIa) is Food and Drug Administration (FDA) approved for severe bleeding in patients with factor VII deficiency. It is, however, being used off-label for patients with normal coagulation systems with life-threatening hemorrhage. Its first use in trauma was reported in 1999, and it is now used in military and civilian settings for trauma patients and for intraoperative hemorrhage.[64,65] Its off-label use has not yet been standardized and transfusion criteria, dosing, and redosing guidelines are still under investigation. Animal studies have indicated prolonged survival times and earlier control of hemorrhage associated with its use, and human case reports suggest that fewer blood products are required in hemorrhaging patients who receive rFVIIa.[64,65,66] Early randomized control trials of rFVIIa for bleeding control during various surgical procedures and in coagulopathic populations did not show reduction in mortality or transfusion requirements.[67,68,69] A 2005 randomized controlled trial of the use of rFVIIa versus placebo found rFVII demonstrated a reduction in the transfusion requirements for blunt trauma patients receiving rFVIIa, and a similar but nonsignificant trend in the penetrating trauma group.[64] Other types of studies, such as case series, meta-analyses and post-hoc analyses of randomized controlled trials have demonstrated trends (albeit statistically insignificant) toward improved outcomes.[70,71,72] Concerns regarding the use of rFVIIa are mainly related to the possibility of promoting thromboembolic complications. This was not observed in the 2005 randomized controlled trial, but has been reported in retrospective reviews.[73] Currently, in combat settings, rFVIIa is judiciously used in patients with life-threatening bleeding requiring massive transfusion.

Damage Control Surgery

During the past 20 years, a new approach to trauma surgery known as damage control surgery (DCS) has been developed. Damage control surgery has been practiced in both civilian and combat settings, and is currently implemented in OEF and OIF. Traditional teaching advocates aiming for a single, definitive operation to repair traumatic injuries. Such an approach stems from the concern that an incomplete operation, or the need for multiple operations, could threaten a patient's overall stability and recovery. However, some definitive repairs of complex injury patterns may take hours to complete. In casualties who arrive in hemorrhagic shock, the lethal triad of coagulopathy, acidosis, and hypothermia may not be completely reversed before and during operative repair of injury. In these patients, metabolic derangements may continue to worsen in the OR, even after control of hemorrhage is achieved. Such patients may have a poorer outcome if subjected to a long, complex operation before physiologic parameters are restored.[74,75]

The principle of DCS is to minimize initial operative time in critically injured casualties by focusing only on the immediately critical actions. These critical actions are: (1) control of hemorrhage; (2) prevention of contamination and gastrointestinal soilage; and (3) protection from further injury. Injuries to the bowel requiring primary anastomosis, or other time-consuming repairs, are left for the subsequent operation(s) (Figs. 28, 29, and 30). Packing is often left in the abdomen. The abdomen is left open and sealed at the skin with a vacuum-assisted dressing to prevent abdominal compartment syndrome. Orthopedic injuries are treated with splinting or external fixation, and vascular injuries may be temporized with temporary intralumenal vascular shunts.[74,75,76]



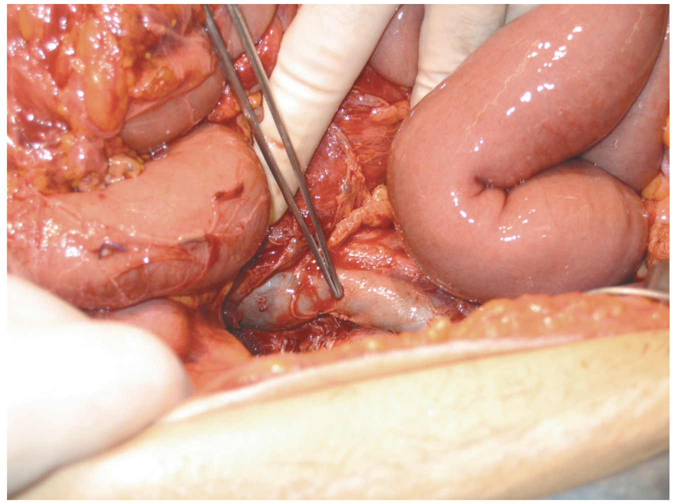


Figure 28. (Top Left) *This was a gunshot wound to the right back creating a large defect in the psoas muscle, laceration of the inferior vena cava (IVC) and destruction of the ascending colon and proximal transverse colon. The patient underwent control and repair of the IVC, packing of the retroperitoneal psoas defect (white pads seen in photo), and stapled resection of the right colon with blind ends left. Distal end of resected colon is seen under suction catheter tip. The proximal resected end was the distal ileum, which is being held in the foreground.*

Figure 29. (Top Right) *Repaired inferior vena cava.*

Figure 30. (Bottom Right) *Completed temporary vacuum-assisted dressing abdominal closure. The bowel and abdominal cavity were irrigated and decontaminated before temporary abdominal closure. The casualty underwent damage control resuscitation – receiving PRBCs, FWB, and rFVIIa – and was transported to a Level III facility less than three hours after his arrival.*

In damage control surgery, an abbreviated operation is performed to control hemorrhage and contain gastrointestinal soilage. After a period of postoperative resuscitation in the ICU, patients may return to the operating room for a definitive procedure.

Following an abbreviated operation, patients are taken to the ICU to reverse the lethal triad through resuscitation and restoration of physiologic parameters. Here, crystalloids and transfusion are continued as needed to restore tissue perfusion and correct acidosis, and the patient is warmed and treated with vasoactive agents if needed. While the aim is to return to the OR in 24 to 48 hours, the definitive operation should not take place until the metabolic derangements are largely reversed. Several complications, including hemodynamic instability, organ failure, or acute respiratory distress syndrome (ARDS) may delay the timing of the second operation. In the definitive operation, abdominal packing and clots are removed and the abdomen is reexplored and washed out. Additional debridement, repair of shunted vascular injuries, anastomosis of bowel, and abdominal closure are performed at this subsequent operation.[74,75]

The timing of definitive surgical repair and abdominal wall closure will often vary based on injury type, severity, status (military or civilian), and nationality of the patient. For example, many US service members will undergo definitive abdominal wall closure following AIREVAC to rearward Level IV or V facilities, while host nation patients typically receive definitive surgical care at the Combat Support Hospital.[77] The combat trauma experience of the US Army 102nd FST in Afghanistan consisted of performing 112 surgeries on 90 patients over a seven-month period. Trauma accounted for 78 percent of surgical cases. Sixty-seven percent of these surgeries were performed on Afghan militia and civilians, 30 percent on US soldiers, and 3 percent on other coalition forces. Mechanisms of injury included gunshot wounds (34 percent), blasts (18 percent), motor vehicle crashes (14 percent), stab wounds (5 percent), and other trauma (7 percent).[77]

The three-step process of abbreviated operative repair, ICU resuscitation, and definitive operative repair of DCS follows the fundamental principle of treating the most immediate life-threats first. While DCR and DCS include several departures from classic ATLS teaching, the basic philosophy of prioritizing injury is the same.[74,75]

Summary

The greatest honor we can pay to war casualties is to use their sacrifice to improve and optimize medical care. The lessons learned from OEF and OIF and prior conflicts have led to numerous advances in combat casualty and civilian trauma care. The CCC environment is vastly different from civilian trauma care settings. Thus, the approach to a combat casualty must take into account many additional logistical factors beyond the type and mechanism of injury. These include: what is the fastest way to reach a medical facility?, who is available to assist upon arrival?, is the area free of hostile fire?, will adequate personnel, blood products, and equipment be available for all those injured?, and, if not, how should casualties be prioritized? Awareness of local and support CCC capacity is as critical to improving patient survival rates as are initial airway, breathing, and circulation interventions.

The recognition of hemorrhage as the major cause of preventable death has led to a paradigm shift in the approach to the bleeding patient. Hemorrhage must be immediately and aggressively addressed with direct pressure, tourniquets, hemostatic agents, and rapid evacuation to a CCC facility. Resuscitation must be geared toward preventing and treating the downward spiral of the lethal triad of acidosis, hypothermia, and coagulopathy. Surgical intervention is directed towards rapid control of hemorrhage and contamination, rather than definitive repair of injury. Combat casualty care continues to evolve. The JTTS and the promotion of peer-reviewed scientific research during the current conflicts is a relatively new phenomenon that fosters investigation and innovation. The many improvements developed from the lessons of prior wars are now saving lives, and the efforts to continue learning will offer the best chance of survival and recovery to those we care for in the future.

Case Study

The following is a copy of the Level II treatment summary from the record of a casualty from OIF that demonstrates most of the aspects of the prior discussions. It details the treatment from appropriate rapid initial care according to the TCCC guidelines, to utilization of DCR and DCS procedures on a critically injured casualty. The treatment summary illustrates how the continuum of care across the different levels of care leads to the survival of a casualty who in prior conflicts undoubtedly would have died.

Casualty # 0822

26-year-old male presented in class IV hemorrhagic shock about 25 minutes after wounding from a sniper round to abdomen. Treatment in field consisted of abdominal dressing over wound and single intravenous catheter access with limited fluid resuscitation. Initial evaluation in Shock Trauma Platoon (STP) revealed entrance wound to right flank with exit out anterior abdominal wall just to right of umbilicus with eviscerated omentum. Initial vital signs: blood pressure (BP) of 80/40, heart rate (HR) of 148, respiratory rate (RR) of 26, and pulse oximeter oxygen saturation (SpO_2) of 98 percent. Additional intravenous access was obtained, blood sent for labs, and antibiotics started and patient taken immediately to the operating room (less than five minutes). Walking blood bank (WBB) activated.

Operative Findings:

- 2,000 milliliters hemoperitoneum with gross fecal contamination
- Large central zone I and right zone II retroperitoneal hematoma with active bleeding
- Abdominal cavity packed and aortic control at hiatus obtained (aortic cross clamp time of 55 minutes)
- Right medial visceral rotation performed
- Grade 5 (pulverized) right colon injury noted
- Multiple lacerations to inferior vena cava from confluence to just inferior to the right renal vein; the aorta is negative for injury
- Grade 3 laceration to third portion duodenum with ischemia

Initial Labs:

pH = 7.1 Base Deficit = -16 Hematocrit = 28 percent

Procedures:

- Initial attempt at inferior vena cava venorraphy but multiple lacerations posteriorly (probable torn lumbars) quickly led to oversew and ligation
- Simple whipstitch closure of duodenum to stop contamination and bleeding
- Stapled resection right colon with blind ends
- Packing right retroperitoneal psoas wound
- Washout peritoneum with rewarming
- Vacuum-pack closure abdominal dressing
- Bilateral lower extremity four compartment fasciotomies (for ligated inferior vena cava and one-hour ischemia time)

Resuscitation by Anesthesia:

- Three liters normal saline
- Six units PRBCs
- 24 units FWB
- 7.2 milligrams rFVIIa

Packaged for En-Route-Care:

- VS: BP = 115/61 mm Hg   HR=147   RR=12 (ventilated) SpO_2=100 percent
- Departed to Level III facility less than four hours after arrival at STP
- En-route-care interventions: blood administration, sedation and paralytics, ventilator management; departing end-tidal carbon dioxide ($EtCO_2$) = 52 mm Hg

Notes from Joint Patient Tracking Application (JPTA) at Level III Facility:

Findings from original STP facility: Gunshot wound to right flank exited near navel. On exploratory laparotomy, patient had a long tear from the confluence of the inferior vena cava to just below the right renal vein. Inferior vena cava oversewn and ligated proximally and distally. Grade 3 injury to the third portion of the duodenum was oversewn. The aorta was cross-clamped at the hiatus (total aortic cross-clamp time was 55 minutes). Right colon with grade 5 injury: colon was resected distal ileum to mid-transverse with blind ends. Gross fecal contamination in peritoneum. Two laparotomy pads packed in right retroperitoneum. One Kerlex™ packing along anterior abdominal wall to exit wound. Vacuum-pack closure of abdomen, bilateral four compartment fasciotomies of lower extremities for ligated inferior vena cava and approximate one hour of ischemia time. Patient received six units of PRBCs, 24 units of FWB, 7.2 milligrams of rFVIIa.

Vital Signs Upon Arrival:

BP = 153/74 mm Hg HR=108 RR=15 SpO_2=100 percent

Level III Facility Admit Note:

Patient was noted to be hemodynamically stable, sedated, and on the ventilator. His abdomen was dressed open and with a negative-pressure dressing (supplied by Jackson Pratts). The right lateral abdomen wound was noted. No other injuries were noted. The coagulation studies were normal and his hematocrit was normal. His base excess was +1. He appeared well-resuscitated. Given the large amount of blood loss at the original operation, will allow further time for hemostasis and he had just recently been taken from the OR. If he remains stable, will reexplore early this a.m.

Next Day Note:

Procedure Note: (1) Abdominal reexploration; (2) Segmental resection of proximal third portion of duodenum; (3) Side-to-side duodenoduodenostomy; (4) Pyloric exclusion; (5) Roux-en-Y gastrojejeunostomy; (6) Retrograde duodenostomy tube; (7) Jejeunostomy feeding tube; and (8) Stamm gastrostomy.

Postoperative Day Three Note:

Patient stable and now off ventilator. Tolerating tube feeds. Fasciotomies closed today. Jackson Pratt (JP) with minimal drainage. Labs normal. Ready for transfer in a.m.

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