Combat damage control surgery

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Background: **Although the use of damage control surgery for blunt and penetrating injury has been widely reported and defined, the use of damage control surgery on the battlefield (combat damage control surgery) has not been well detailed.**

Discussion: **Damage control surgery is now well established as the standard of care for severely injured civilian patients requiring emergent laparotomy in the United States. The civilian damage control paradigm is based on a "damage control trilogy." This trilogy comprises an abbreviated operation, intensive care unit resuscitation, and a return to the operating room for the definitive operation. The goal of damage control surgery and the triology is avoidance of irreversible physiological insult termed the *lethal triad*. The lethal triad comprises the vicious cycle of hypothermia, acidosis, and coagulopathy. Although the damage control model involves the damage control trilogy, abbreviated operation, intensive care unit resuscitation, and definitive operation, all in the same surgical facility, the combat damage control paradigm must incorporate global evacuation through several military surgical facilities and involves up to ten stages to allow for battlefield evacuation, surgical operations, multiple resuscitations, and transcontinental transport.**

Summary: **Combat damage control surgery represents many unique challenges for those who care for the severely injured patients in a combat zone. (Crit Care Med 2008; 36[Suppl.]: S304–S310)**

Key Words: damage control; exploratory laparotomy; Operation Enduring Freedom; Operation Iraqi Freedom

Although civilian damage control surgery has been widely defined, damage control surgery on the battlefield (combat damage control surgery) does not have the same distinction. To understand the combat damage control concept, it is imperative to first define the philosophy of damage control surgery and then to define the current system for damage control in civilian trauma centers. In this article, I also contrast this concept with my view of combat damage control surgery (as it is currently being used in Operation Iraqi Freedom and Operation Enduring Freedom). Performing damage control surgery in a combat zone, needless to say, is associated with many pitfalls and challenges, and some say it is an almost impossible task (1–3). We believe strongly that aggressive damage control surgery has been, is currently, and will be carried out successfully by combat surgical teams (4–7).

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What Is Combat Damage Control Surgery?

Combat damage control requires many stages resulting from the necessity of multiple evacuation stages involved in moving the combat-injured U.S. military personnel from the battlefield to the continental United States. Figure 1 provides an overview of evacuation through the different military levels (with progressive capabilities from the austerity of the battlefield to the near-equivalent civilian level I trauma center capability of the European and U.S. Army medical centers) (8). Of note, military levels of care DO NOT correlate in anyway with the civilian trauma care levels designated by the American College of Surgeons.

With the unique requirement for intratheater and global evacuation arises the similarly unique requirement for a modified, multistaged damage control surgical approach.

My goal is to define combat damage control and its many stages so as to provide a platform for analysis of our current capabilities. In as much, we must challenge the current situation allowing for maximal improvement at each stage in military combat damage control in current and any future conflicts.

Combat statistics of died of wounds after arriving at a surgical facility removing (severe head injuries, approximately 15%—high mortality, and all extremity wounds, approximately 55% of combat wounds—low mortality), it becomes apparent that improving the mortality of damage control patients is the only way to significantly decrease the overall mortality rate of combat wounded (9, 10). After a damage control surgery, acidosis, hypothermia, and coagulopathy are predictive of mortality (11). Therefore, to decrease the rate of mortality of damage control patients (and the overall mortality rate of wounded reaching surgical facilities), logically, the ability of far-forward surgical teams to warm, resuscitate, and correct coagulopathy must be optimized.

Damage Control Surgery

Damage control surgery is based on a U.S. Navy term and process used to describe "the capacity of a ship to absorb damage and maintain mission integrity" (12). When a Navy ship or submarine has taken hostile fire, the sailors, at all costs, immediately put out all fires and stop any flooding. The surgical analogy is to stop all hemorrhaging and gastrointestinal soilage as fast as possible.

The need for speed in severely injured trauma patients is the avoidance of the trauma "lethal triad." The lethal triad comprises the vicious cycle of hypothermia, acidosis, and coagulopathy (13). The acidosis arises from hypovolemic shock and inadequate tissue perfusion (14). Hypothermia stems from exsanguinations

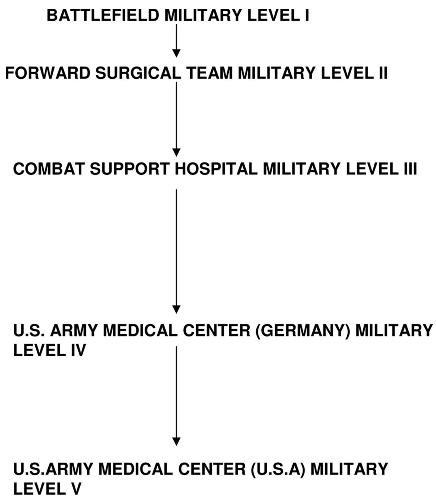

Figure 1. Combat-injured evacuation route.

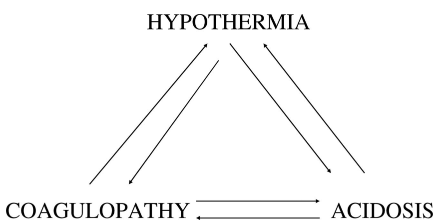

Figure 2. The "vicious cycle" of the "lethal triad."

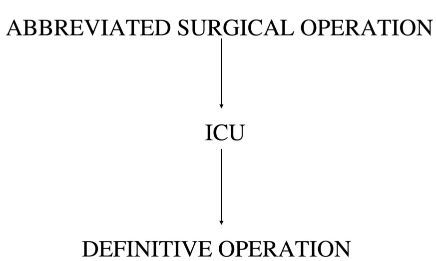

Figure 3. Damage control trilogy. *ICU*, intensive care unit.

and loss of intrinsic thermoregulation (15, 16). Coagulopathy is from hypothermia, acidosis, consumption of clotting factors/platelets, and blood loss (17–20). Coagulopathy in turn causes more hemorrhage, which exacerbates acidosis and hypothermia fueling the vicious cycle (Fig. 2). When in full fruition, the vicious cycle of the lethal triad is almost uniformly fatal.

In 1993, Rotondo et al. in a landmark paper reported the successful use of an abbreviated operation in trauma patients to avoid the lethal triad and coined the phrase "damage control" with a mortality rate of 50% (21). Many trauma centers have reported similar results with damage control approaches to the severely injured trauma patient, and it is now common place and considered the standard of care (22–27).

Table 1. Goals for postoperative resuscitation in the intensive care unit[41]

Hypothermia
- Temperature >36°C
Acidosis/perfusion/volume status
-Base deficit > −5
-Lactate normal
-Urine output >50 cc/hr
Coagulopathy
- Prothrombin time <15 secs
- Partial thromboplastin time <35 secs
- Platelet count >50,000
Ventilator
- FIO_2 <50%

Adapted from Moore E, Feliciano D, Mattox K. Trauma. 5th edition. New York: McGraw-Hill Publishers, 2004.

Although originally reported as an approach to severe abdominal trauma, the damage control process has evolved to cover all anatomic regions, including thoracic trauma, neurologic trauma, and extremity trauma, especially in the multiple system-injured trauma patient (28–36).

Of historical note, the second author of the landmark study by Rotondo et al. is Dr. William Schwab, U.S. Navy Ret. (21).

Civilian Damage Control Surgery

Civilian damage control surgery is now well established as the standard of care for severely injured patients in the United States. The civilian damage control paradigm is based on a "damage control trilogy" (23, 37). This trilogy comprises: a) abbreviated operation; b) intensive care unit (ICU) resuscitation; and c) return to the operating room for the definitive operation (see Fig. 3).

Goals of the "abbreviated operation" include stopping surgical hemorrhage and secondarily to stop all gastrointestinal succus soilage in the shortest duration as possible. After operative control of bleeding and soilage, patients receive continued resuscitation including red blood cells, fresh-frozen plasma, and platelets in the ICU as needed using the tenets of damage control resuscitation, described in another article, while also limiting crystalloid fluids (13, 38). Patients are rewarmed while full laboratory analysis is undertaken with the basic goal of "normalizing" the patient using the guideline values found in Table 1 (39). Each patient undergoing these operative procedures and ICU care requires significant resources, both in personnel and logistics.

When the patient is hemodynamically stable with normal laboratory values, ventilatory status, and body temperature approximating the previously noted goals, the patient is then returned to the operating room for the "definitive operation." This second operative procedure often occurs 24 to 36 hrs after the initial operation. Definitive operations include bowel anastomoses, colostomy maturation, definitive vascular repair where an interposition vascular shunt had been previously placed, removal of hemostatic packing, and closure of abdominal fascia where feasible. Subsequently, in the ICU, postoperative care progresses toward the ultimate goal of discharge to home or a rehabilitation center.

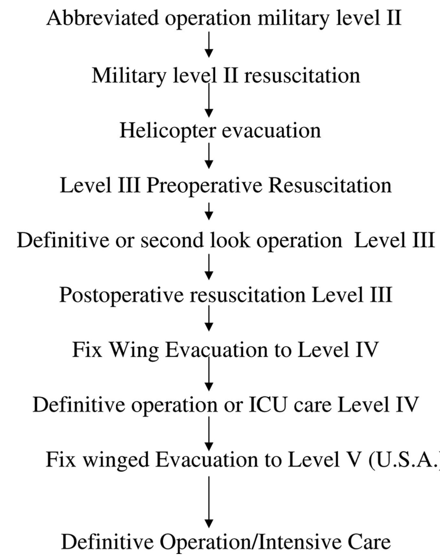

Figure 4. Combat damage control surgery. *ICU*, intensive care unit.

The documented mortality for the damage control surgical procedures in patients requiring a damage control laparotomy is approximately 50% with a documented morbidity of approximately 40% (40).

In review, the civilian level I trauma center damage control model involves the damage control trilogy: abbreviated operation, ICU resuscitation, and definitive operation, all in the same surgical facility.

U.S. Military Damage Control Surgery

Combat damage control involves up to ten stages to allow for battlefield evacuation, surgical operations, and resuscitations. Figure 4 outlines the basic outline for the multiple necessary stages in combat damage control. These stages are subsequently defined.

Table 2. U.S. Army forward surgical team personnel, equipment and blood supply (Military level IIb Facility)

Total personnel	20
General surgeons	3
Orthopedic surgeon	1
Certified registered nurse anesthetist	2
Registered nurse	3
Operating room tech	2
Medic/licensed practical nurse	8
Medical administrator	1
Operating tables	2
Packed red blood cells	20–50

Battlefield to Initial Forward Surgical Facility (Military Level II Facility)

Battlefield Trauma Care. There has been a great focus on the care of battlefield injured by the military medic and individual soldier as the "first responder" by initiation of a new program of tactical combat casualty care as outlined in a previous article (41). The combat medic faces unique challenges to provide trauma care to very severely injured personnel as well as provide care under hostile fire (42).

Currently, compressible extremity arterial hemorrhage is one of the most common preventable causes of mortality on the battlefield. Tourniquets applied correctly and rapidly can provide excellent hemostasis and minimal complications (43). Today, each individual soldier going into a combat zone is equipped with a commercially available windlass tourniquet after extensive study of efficiency (44).

Bleeding from large soft tissue injuries with large surface areas with small vessel bleeding is also a cause of mortality and morbidity. The hemostatic battlefield dressing comprised of chitosan has been used successfully by military medics and is now given to every U.S. soldier deployed in a combat zone (45, 46).

Battlefield Resuscitation. Following the landmark study by Bickell et al., which revealed a decreased mortality in truncal penetrating injury if intravenous fluids were withheld in the preoperative patient, "hypotensive resuscitation" for penetrating truncal trauma has now become the preferred approach for most civilian trauma surgeons (47, 48). However, the basis of this approach lies in the reports of Cannon and Beecher, from World War I and World War II, respectively (49, 50). The concept of hypotensive resuscitation is based on simple physics: bleeding increases and blood clots on bleeding arteries "pop off" with increased blood pressure, or in Dr. Cannon's words in 1918, "overcome the obstacle offered by a clot" (49, 51).

Although the civilian study by Bickell et al. in Houston withheld intravenous fluids until surgical hemostasis was obtained, these studies were in an urban environment with very short transport time from site of injury to surgical facility (47). The military combat wounded represents a unique situation in which evacuation times are dependent on geography, weather, enemy activity, and very large distances. These situations that require a prolonged evacuation time make the practice of withholding intravenous fluids for penetrating truncal wounds difficult is some cases. The U.S. Army has adopted a practice of "hypotensive resuscitation," although more correctly defined as limited fluid crystalloid resuscitation before surgical intervention when feasible (41). This practice uses crystalloid or colloid (for example, Hextend, BioTime, Inc., Berkeley, CA) administered by a combat medic and the amount of fluid is titrated to a palpable radial pulse and neurologic function (in the nonbrain-injured) (52).

Battlefield Evacuation. The individual injured on a combat zone after initial evaluation and treatment by individual soldiers and subsequently by a medic will be evacuated to the nearest surgical military surgical facility. Depending on weather, distance to the surgical facility, enemy activity, and severity of the wounds, the patient will be transferred by helicopter or ground transport ambulance. Patients are typically observed by a flight medic. The most common helicopter used for initial transport is the UH-60 Blackhawk helicopter. As a result of internal dimensions, aircraft movement, and rotor noise, monitoring and/or inflight interventions are extremely challenging.

Abbreviated Operation. After arrival to the first capable surgical military facility (military level IIb; for example, U.S. Army forward surgical team [FST]), the hemodynamically unstable damage control patient will undergo immediate operation (53). The personnel and basic capabilities of an FST are described in Table 2. Although most FSTs do not have x-ray capability, the majority of FSTs have a portable ultrasound, which is used to evaluate the abdomen for free fluid in blunt trauma and to evaluate for cardiac injury in both blunt and penetrating trauma (54–58). Ultrasound has been demonstrated to be of little clinical significance in civilian penetrating trauma but may have a triage application in a mass casualty situation with multiple patients with fragmentation wounds to the abdomen (59, 60).

The majority of personnel assigned to far-forward surgical facilities undergo predeployment training at one of the military civilian trauma training sites (U.S. Army at Ryder Trauma Center in Miami, U.S. Air Force at the Maryland Shock Trauma Center, and U.S. Navy at Los Angeles County Trauma Center). During this training, physicians, nurses, nurse anesthetists, and medics participate in didactic lectures, skills labs, patient simulators, and active civilian trauma care (61–63).

The goals of the abbreviated operation are the same as in the civilian trauma center: a) cessation of all surgically correctable hemorrhage; and b) avoidance of gastrointestinal soilage. The majority of laparotomies in combat damage control involve early laparotomy pad packing for hemostasis (64–66). As a result of the adverse effects on body core temperature by the opening of the peritoneal cavity as a function of time, most combat damage control operations are as rapid as possible with the goal of less than 90 mins (67).

Orthopedic damage control includes rapid splinting or placement of external fixators. External fixation of bone fractures offers the logistic advantage of weight and stabilizes the extremity for subsequent vascular repair (68). Vascular injury at military level II facilities includes temporary placement of a interposition shunt (or simple ligation) and distal compartment fascial release (69, 70). Fasciotomy is extremely important in military scenarios because the patient will not be continuously observed during transport and is performed therapeutically as well as prophylactically (71, 72). All damage control patients undergoing a laparotomy have the abdominal fascia left open to avoid the complications of unobserved abdominal compartment syndrome (73–76).

Initial Postoperative Resuscitation

The postoperative resuscitation in military level II facilities is hampered by the options available for blood and blood product replacement. Most military level

Table 3. U.S. army combat support hospital personnel, operating tables, blood and blood products supply (Military Level III)

Total personnel	250–500
General surgeons	3–7
Orthopedic surgeons	3–5
Urologist	1
Obstetrics/gynecologist	1
Neurosurgeons	1–2
Oral maxillofacial surgery	2
Ear, nose, and throat	0–1
Internal medicine	1–5
Anesthesiologists	1–2
Certified registered nurse anesthetist	5–12
Registered nurses	50
Operating rooms	3–5
Packed red blood cells	110–150
Fresh frozen plasma	30–50

IIb (for example, FST) facilities carry 20–50 of O^+ or O^- packed red blood cells only. Availability of recombinant factor VIIa is available at some facilities and other military level II facilities also have the ability to crossmatch (for major ABO compatibility) and transfuse whole blood. Fresh-frozen plasma freezers are being deployed with some FSTs at present, but it is not a universal capability. Thermoregulation is not universal but includes Baer Huggers (Arizant Healthcare, Eden Prairie, MN), environmental control units (heaters), and intravenous fluid warmers (77). When the patient is clinically determined to be hemodynamically stable or resources for resuscitation have been exhausted (for example, blood triage), arrangements are made for transport to a military level III facility (for example, U.S. Army combat support hospital [CSH]). Although the goals of resuscitation at this stage are the same as in civilian damage control (Table 1), these goals often cannot be met and are modified by logistics and patient volume. As a result of the limited blood storage capability of the far-forward surgical teams, the ability to provide optimal blood replacement to all patients in a mass casualty situation is not feasible. The concept of "minimal" acceptable resuscitation would be valid in this situation just as it is being practiced in the current damage control capabilities in American rural surgical facilities. Minimal acceptable resuscitation is the practice of dividing the available blood resources among the maximum number of patients using the absolute "minimal" amount of blood and blood products to allow for patient viability (78, 79).

Evacuation From Forward Surgical Facility (Military Level IIb) to Combat Support Hospital (Military Level III)

The majority of postoperative damage control patients are transported from a military level II facility (for example, FST) to the military level III facility (for example, CSH) by a Blackhawk UH-60 helicopter. One of the main concerns during this usually short (<30-min) flight is thermoregulation. Patients in civilian trauma centers can lose up to 2°C during a short intrahospital trip to the radiology department with wool blankets only (80). Active convection heating devices have been shown to decrease heat loss during transport of ICU patients and in evacuation of civilian trauma patients (81, 82). Currently, multiple heating-generating mechanisms are being tested for approval in rotary aircraft, and the main attempts at maintaining body core temperature involve passive methods to combat heat loss. Currently, one of the most successful measures of maintaining core body temperature during transport involves placing the live patient into a converted body bag for transport coupled with two wool blankets and a reflective blanket, coined a "hot pocket." The patient is monitored during flight by a medic with a Propaq vital sign monitor (Protocol Systems Inc., Beaverton, OR). As previously mentioned, the limited internal dimensions, noise, and movement in the Blackhawk UH-60 helicopter make monitoring and treating a patient in flight very challenging.

Combat Support Hospital (Military Level III Facility)

The capabilities of the military level III consist of a complete or partial CSH. The capabilities of the CSH are the most robust within a combat zone. Personnel and surgical capability of the U.S. Army CSH are listed in Table 3 (82). Level III facilities have full plain x-ray capabilities, fluoroscopy, and most have computed tomography. The computed tomography scan is of great value when evaluating patients with multiple fragmentation wounds (60).

Preoperative Resuscitation at Military Level III Facility

Depending on distance from injury point, patients also arrive directly from the battlefield to the military level III facility and will then undergo their abbreviated operation and start their journey down the combat damage control pathway from there. As the battlefield matures, this rate of direct admission from the battlefield can approach 90%.

Postoperative damage control patients from the military level II facilities often arrive after even a short duration rotary wing transport: hypothermic, hypovolemic, acidotic, and coagulopathic. These patients represent the most critically injured because they are placed on a helicopter before adequate reheating and blood volume resuscitation as a result of ongoing nonsurgical bleeding and the lack of blood for further transfusion or the need to triage existing blood supplies. Because most military level IIb facilities (for example, FST) do not have fresh-frozen plasma, platelets, or cryoprecipitate at this military level (or limited supply of each) and the ability to draw, crossmatch, and transfuse whole blood is not universally available or feasible, patients can arrive to the CSH underresuscitated. Rushing these patients to the operating room at the military level III facility and exposing them to the massive heat loss of reopening of a body cavity could be fatal. In our experience, these critically ill patients who are in the vortex of the lethal triad should be brought immediately to the ICU at the level III facility for aggressive attempts to restore body core temperature, volume status, hemoglobin >7 g/dL, and the same goals as listed for civilian damage control (Table 1). Once rewarmed, fluid and blood resuscitated, and hemodynamically stable, patients can return to the operating room. All patients arriving at a level III facility also undergo a "tertiary" trauma examination looking for undocumented or missed injuries (83, 84).

Definitive Surgery or 'Second-Look' Operation at a Military Level III Facility

After rewarming and resuscitation, the patient is brought back for at least a second look and repacking. All abdominal packs need to be removed before 72 hrs after the initial placement as a result of increased risk for infection after this time period (85). Also, a second look can provide for an opportunity to diagnose any missed injuries during the initial damage control procedure (86). If the clinical decision is made to perform the definitive operation, the bowel is anastomosed to allow for continuity, colostomies are matured, vascular shunts are removed, and vein interposition grafts are placed. If the patient is still clinically coagulopathic, the operation may be turned into a simple second look with packs replaced and the patient returned to the ICU. Unless the peritoneal contents are without any clinical evidence of edema (a very rare occurrence in any damage control laparotomy), the abdominal fascia remains open as a result of further evacuation and limited ability to observe for abdominal compartment syndrome.

Postoperative Resuscitation at a Military Level III Facility

The postoperative resuscitation at the military Level III facility has the same goals of resuscitation as for the initial abbreviated operation because the patient will need to be stable for the unique ability to fly by fixed wing or a combination of a rotary wing and then fixed wing to the next military level of care, military level IV in Europe.

Evacuation From Military Level III to a European Medical Center (Military Level IV)

Many military-level facilities are located on or close by to an airfield allowing for fixed-wing transport (for example, C130 Hercules or C17 Globemaster). If the military level III facility is not physically located on the airfield, a short rotary wing flight to the airfield will need to be undertaken with a UH-60 Blackhawk or CH-47 Chinook with a medic, registered nurse, or physician accompanying depending on patient severity and personnel availability. These patients undergoing rotary wing evacuation are then evaluated by the accepting airfield physicians and the patient's stability is assessed for fixed-wing global evacuation. The postoperative damage control patient deemed stable for transport is then placed on a C17 or C130 fixed-wing aircraft. Personnel on these transports depend on the patient's condition. All ventilated patients are monitored by a U.S. Air Force critical care air transport team (CCATT). The CCATT team is the world's gold standard for air transport of critical care patients. The CCATT team is a three-member team consisting of a physician (specializing in critical care, pulmonology, surgery, and so on), a critical care nurse (RN), and a respiratory technician (87). These patients are flown in the equivalent to a "flying ICU" by the CCATT team to a U.S. Army medical center (military level IV) in Europe (88, 89). As a result of risk factors for deep venous thrombosis, including major operation and prolonged air evacuation, damage control patients are started on sequential compressive devices and Lovenox (enoxaparin; Sanofi-Aventis, Bridgewater, NJ) as soon as feasible (90–92).

Preoperative Resuscitation at a Military Level IV Facility

The postoperative combat damage control patient will arrive at the military level IV facility (for example, European U.S. Army medical center) from the CCATT, which provides a "flying ICU," and the patients at this point should arrive in a stable hemodynamic and near fully resuscitated condition. After 12 to 24 hrs, many patients are brought back to the operating room.

Definitive Operation or Postoperative Intensive Care Unit Care at a Military Level IV Facility

When the patient is clinically stable, the patient is brought back to the operating room as needed and may undergo abdominal washout, definitive operation, and attempted abdominal fascial closure. Orthopedic external-fixation and splints are re-evaluated.

Global Evacuation to Continental United States of America Military Level V Facility

Postoperative damage control patients who are assessed as stable enough to endure a transatlantic flight without deterioration in his or her medical condition are considered as potential candidates for evacuation back to the continental United States. Patients who are transferred in a stable condition but requiring mechanical ventilation are evacuated by the previously mentioned U.S. Air Force CCATT. The patients can be taken to any one of many U.S. Army, Navy, or Air Force medical centers in the United States.

Continental United States Medical Center Care

The combat damage control patient arriving at the U.S. military medical center in the continental United States undergoes any further care, cosmetic surgery, and long-term rehabilitation as necessary. Many combat damage control patients arrive with an open abdomen and further attempts at primary closure are undertaken or a staged-closure technique is initiated. Damage control patients with a significant burn injury are flown to the U.S. Army Institute of Surgical Research Burn Center in Texas. Severely burned patients are evacuated from the European level IV facility by the U.S. Army burn flight team, which has similar capabilities to the CCATTs but with extensive burn care expertise (93).

CONCLUSIONS

Combat damage control, while adhering to the tenets of civilian damage control, is a far more prolonged and complicated process involving a combat zone, three continents, and multiple stages. The process described represents a new standard for the U.S. military.

Improving combat damage control surgery is one of the only ways to decrease the mortality of combat wounded personnel arriving with vital signs at a combat surgical facility in the near future. All efforts must be made to reexamine and improve the areas of combat damage control surgery that are considered "austere" to bring them up to the capabilities of civilian level I trauma centers.

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