Complex Dismounted IED Blast Injuries: The Initial Management of Bilateral Lower Extremity Amputations With and Without Pelvic and Perineal Involvement

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The magnitude of recent combat blast injuries sustained by forces fighting in Afghanistan has escalated to new levels with more troops surviving higher-energy trauma. The most complex and challenging injury pattern is the emerging frequency of high-energy IED casualties presenting in extremis with traumatic bilateral lower extremity amputations with and without pelvic and perineal blast involvement. These patients require a coordinated effort of advanced trauma and surgical care from the point of injury through definitive management. Early survival is predicated upon a balance of life-saving damage control surgery and haemostatic resuscitation. Emergent operative intervention is critical with timely surgical hemostasis, adequate wound decontamination, revision amputations, and pelvic fracture stabilization. Efficient index surgical management is paramount to prevent further physiologic insult, and a team of orthopaedic and general surgeons operating concurrently may effectively achieve this. Despite the extent and complexity, these are survivable injuries but long-term followup is necessary. (Journal of Surgical Orthopaedic Advances 21(1):8–14, 2012)

Key words: combat blast injury, complex dismounted IED injury, multiple limb amputations, open pelvic injury, damage control surgery

Introduction

The Evolution of Modern Battlefield Mechanisms of Injury

Combat injuring patterns continue to define the outcomes of war casualties. Historically, high rates of early mortality from exsanguination and rapid sepsis existed for those wounded in action during the Civil War through World War II (1,2). During that time, many casualties died of simpler gunshot and blast wounds that could to define have been appropriately treated with modern advances in the use of field tourniquets, antibiotics, and rapid evacuation to in-theater combat hospitals (3–6). Adaptive combat surgical measures, such as field amputations, have theoretically lowered early mortality rates for extremity injuries; however, the overall percentage of casualties dying from non-survivable hemorrhage remains relatively similar in modern conflicts despite contemporary medical advances (7,8).

In the current Global War on Terrorism (GWOT), blasting ordinance continues to be the predominate mechanism of battlefield injury (9-11). The Improvised Explosive Device (IED) remains the hallmark source of blast munitions used against United States and coalition troops fighting in Operation Enduring Freedom (OEF), the

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present combat operation focused in Afghanistan that recently passed its 10-year milestone. Retrospective studies show that extremity IED wounding patterns are consistently more common than abdominal, thoracic, or head trauma (12-14). The escalation of combat missions during this conflict has been associated with an increase in troop exposure to IED's and a resulting array of complex polytrauma injuries. Open and closed lower extremity (LE) fracture patterns and thoracolumbar spinal injuries are well-documented casualties sustained during mounted IED explosions where soldiers are protected within armored vehicles (15,16). However, the most complicated and challenging combat casualties that have emerged are those sustained by troops encountering buried IED's during dismounted, unprotected walking patrols. Of this variety, the most critical injuring pattern involves bilateral proximal-level LE amputations with open pelvic fractures and destructive blasting wounds to the perineum and genitourinary (GU) system (17). Historically this injury pattern is not new or unique to this conflict; however, a few sources indicate that the number and frequency of these complex dismounted IED injuries have dramatically increased in 2010 (18,19). The exact reason for this increase is unknown, but it is likely multifactorial and attributable to combat tactics specific to this war and improvements in combat casualty care. Nevertheless, collected injury data shows the number of OEF triple-limb amputees almost doubled during 2010 relative to the total of those seen in the previous 8 years of previous fighting (18). The overall number of those fatally injured from this mechanism of injury remains unknown. However, the alarming frequency of multi-limb amputees now returning from OEF combat operations has sparked concern for countermeasures to prevent these mutilating injury patterns and effective treatment strategies aimed to maximize their overall medical care and rehabilitation.

Dismounted IED Injury-Specific Challenges

Casualties surviving dismounted IED blasts can be placed into two subcategories: (1) lower-energy IED exposure (whether secondary to ordinance potency or proximity to the explosion) that yields an assortment of LE fractures (both open and closed), the potential for nonsalvageable mangled LE injuries, various grades of soft tissue blast wounds and/or minor perineal and GU blast involvement; versus the (2) higher-energy IED encounters with traumatic bilateral LE amputations at various levels, associated upper extremity (UE) open fractures or amputations proximal to the wrist, pelvic ring injuries (both open and closed) and destructive blasting damage to the perineum and GU system (Fig. 1). In these patterns, unstable open pelvic ring injuries are not uncommon. Intra-abdominal hollow and solid organ involvement are



FIGURE 1 Characteristic representation of a complex dismounted IED casualty with three traumatic extremity amputations and an unstable, open pelvic ring injury. The patient is being prepped for the index surgical procedure after trauma bay resuscitation and previous pelvic stabilization with a commercial binder.

also more frequent in the higher-energy IED subset. Although intra-cranial combat injuries can be associated with high risks for early death, they tend to be less regular in either of these injury patterns (7,17).

The ancient Greek physician Hippocrates believed that, "war is the only proper school for surgeons" (20). This could not be closer to the truth when it comes to care of these extremely complex casualties. The dismounted IED mechanism of injury carries significant morbidity and mortality. Multiple organ systems are affected, making initial assessment and care extremely challenging for combat surgeons. Until recently, there have been no specific treatment guidelines for the early management of these injuries (21). Analogous civilian injury patterns are rare and typically limited to case reports of critically ill and mangled survivors of high-speed motor vehicle accidents or pedestrians struck by trains (22-25). In addition, the few previously reported depictions of similar blast injuries accumulated from prior decades of war offer a minor comparison to the increasing frequency of complex dismounted IED encounters seen in OEF (26–27). In April 2011, The Joint Trauma Theater System released a clinical practice guideline in response, offering a suggested treatment algorithm for the "Management of high bilateral amputations" (21).

Recent studies of the GWOT show a decline in the number of soldiers killed in action during this conflict, with success attributed to the widespread use of body armor and helmets, the routine use of field tourniquets to control hemorrhage, expedited medevac transports to downrange combat hospitals staffed by trained medical personnel, and the increasingly successful implementation of haemostatic resuscitation (4,28,29). As a result, soldiers are surviving more devastating injury patterns. This has forced contemporary military surgeons to expand the fundamentals of trauma care for successful treatment of these complex IED blast injuries.

Early survival of this injury pattern is predicated upon emergent hemorrhage control with reversal of acidosis and hypercoagulability. On a rare occasion, intra-cranial pathology leads to early mortality. Rapid medevac to tertiary level in-theater combat facilities provides the most advanced resources for life-saving measures. Haemostatic resuscitation using a 1:1:1 ratio of packed red blood cells (PRBC's) or whole blood, fresh frozen plasma (FFP), and platelets is the most successful protocol for massive transfusion needs (30). These patients arrive to treatment facilities critically decompensated with multiple limb amputations and a variety of peri-pelvic and perineal blast injuries. They require the most emergent care focused on the principles of Advanced Trauma Life Support (ATLS) and damage control surgery.

Hospital resources can quickly become depleted during the initial care. An abundant blood bank is paramount to meet the demands of the massive transfusions. Surgical hemostasis using an efficient and orchestrated compliment of general surgeons and orthopaedists working together concurrently can provide life-saving control of exsanguinations. Wound decontamination is an equally important part of the initial surgical treatment paradigm. Infection control begins at the index procedure and remains a critical aspect of subsequent surgeries. Mortality extended beyond the first days after injury is typically secondary to sepsis and multi-organ system failure.

Initial Management: The Trauma Bay Evaluation

A dismounted IED casualty associated with multiple extremity amputations typically arrives in extremis shortly after injury and represents one of the most difficult and resource intensive injury patients. As with all critically injured patients, initial trauma bay evaluation and resuscitation must be focused, coordinated, and timely. Significant resources are needed to deal with these injury patterns in an effective manner; these include multiple trauma and orthopedic surgical teams (including nurses and technicians), large amounts of blood products, and extra anesthesia support. The focus in the trauma bay follows ATLS principles in that an adequate airway is quickly secured, obvious hemorrhage is controlled, and resuscitation begins with a goal of rapid movement to the operating room for more definitive and controlled lifesaving measures. Pre-hospital personnel are often unable to obtain IV access; this is a result of depleted circulating volume with profound shock and/or traumatic upper extremity injuries, such as amputations or complex fractures that do not allow peripheral access. The placement

of intra-osseous lines is sometimes a useful adjunct to begin resuscitation prior to central venous access. Resuscitation follows damage control guidelines and mandates the activation of massive transfusion protocols upon casualty arrival; early consideration for the use of Fresh Whole Blood resuscitation may be necessary if blood resources are limited or expected because of mass casualty scenarios (31,32)

These patients may arrive with CPR in progress. When signs of life are present, confirmed by standard measures including Focused Abdominal Sonography for Trauma (FAST) ultrasound for cardiac activity, organized EKG activity, and papillary reaction, consideration of resuscitative thoracotomy should be given (33). This may allow for trauma bay resuscitation to ensue with proximal hemorrhage control that can be later modified. A judicious practice of resuscitative thoracotomy is recommended only for those patients undergoing reasonable periods of CPR. Efficient and coordinated ATLS measures, along with haemostatic resuscitation, have been found effective in maintaining initial stability in these severely injured patients (17).

Once the airway is secured, IV access obtained, and haemostatic resuscitation begun, a focused and systematic assessment of the injury pattern will identify those patients with complex open or unstable pelvic injuries versus those with high bilateral amputations without pelvic involvement. During this assessment, tourniquets placed in the field should be re-evaluated and reinforced or replaced with pneumatic tourniquets if necessary. Additionally, temporary control of pelvic volume with circumferential compression sheet or pelvic binder stabilization may be indicated in unstable pelvic ring injury patterns (34,35). Adjunctive studies should be limited to trauma bay radiographs of the chest and pelvis, with selected extremity views if patient stability permits. CT scanning should be generally avoided and used only when objective measures of head injury suggest the possible need for neurosurgical intervention. Once these steps are taken, the patient is then emergently transported to the operating room for initial damage control surgery.

The Index Surgical Procedure

Hemorrhage control and surgical debridement are the priorities of the index operation. Additional secondary priorities include: control of pelvic volume and long bone fractures through external fixation, completion amputations to the most distal viable level, bladder repair, and potential colonic diversion in cases of perineal blast injuries or open pelvic fractures. A multidisciplinary team approach using general and orthopaedic surgeons working simultaneously is the most effective method for care of these unstable patients. Prolonged operative times should be avoided to prevent second hit physiologic insults in patients presenting with the dreaded triad of hypothermia, acidosis, and hypercoagulability. Although concurrent haemostatic resuscitation is an essential part of normalizing physiology during the index surgery, reasonable endpoints must be established to terminate further surgical insult in critically unstable patients. Heroic measures to hit the "home run" and provide comprehensive surgical care for all injuries must be avoided during the index surgery (Fig. 2).

The specific technique utilized for surgical hemostasis varies dependent upon the proximity of blast injury to the pelvic and abdominal regions. Casualties presenting with bilateral LE amputations even at the long abovethe-knee (AKA) level, with minimal pelvic or perineal involvement, can be effectively managed with temporary tourniquets and definitive distal extremity vessel ligation. On the contrary, more proximal level amputations and those casualties with severe open pelvic or abdominal injuries require temporizing proximal vascular control of the iliac vessels via a celiotomy or retroperitoneal approach. In the case of massive intra-pelvic bleeding, the final level of vascular control is a balance of preventing exsanguination and maximizing the length of the amputation(s). Every effort should be made to advance temporary vascular control to the most distal and viable level. This is critically important in cases requiring hip disarticulation or hemipelvectomy where definitive proximal iliac vessel ligation can lead to future tissue ischemia, gluteal flap necrosis and a more proximal revision amputation level.

The combination of laparotomy and external fixation has been previously recommended for control of unstable



FIGURE 2 Image of the same patient at the completion of an expedited initial operative intervention in which proximal iliac surgical hemostasis was temporarily achieved through an exploratory laparotomy with associated sigmoid diversion, wound debridement, completion amputations with distal vessel ligation and pelvic external fixation.

and open pelvic ring injuries (Fig. 3) (36). Reduction of pelvic volume with external fixation assists in bleeding tamponade and allows for continued soft tissue access for serial debridements (Fig. 4). Stabilization may be performed using either iliac crest or supra-acetabular external fixation with the latter yielding the greatest pelvic control but dependence upon surgeon familiarity and available fluoroscopy. Occasionally, moderate to severe



FIGURE 3 Intraoperative inlet fluoroscopic view depicting the use of a reduction clamp placed through the open celiotomy wound to reduce and stabilize the open pelvic ring injury with supra-acetabular external fixation.



FIGURE 4 Image of the open pelvic and amputated LE extremity blast wounds after treatment with antibiotic beads and serial debridements.

intra-pelvic bleeding requires the addition of retroperitoneal pelvic packing for adequate hemostasis. This technique has been found to be effective in other highenergy pelvic injuries (37,38). On a rare occasion, definitive iliac ligation and/or surgical hemipelvectomy are accepted damage control measures to handle the most severe cases of massive retroperitoneal bleeding and open pelvic ring injury (39–41).

Surgical management of intra-abdominal hollow viscus or solid organ injuries can be effectively stabilized through the celiotomy at the index procedure. Interruption of the sigmoid colon with later diversion is a previously reported and effective measure to decrease contamination in cases with perineal and peri-pelvic open wounds (42–44). Damage control urologic procedures, such as bladder repair or midline suprapubic catheter placement, may also be necessary during the primary procedure as the measurement of urine output is critical in effectively managing resuscitation (45).

Adequate index surgical debridement is a critical step in preventing later risks of infection. IED blast wounds carry a large degree of gross contamination and systematic sharp debridement of all nonviable skin, subcutaneous tissue, fascia, periosteum, and bone must be performed early. It is prudent to expand the zone of injury back to viable, healthy soft tissue and bone during each debridement. Due to the high energy, the zone of tissue ischemia tends to evolve over several days and serial debridements are necessary to reduce the bioburden and soft-tissue necrosis. Due to the elevated risks of early infection, combat wounds should be left open with closure reserved after later surgical encounters (1,3,12). Revision of traumatic amputations must be performed at the most distal and viable level retaining traditional or even atypical rotational flaps for later coverage. It must be emphasized that in the multiple-limb amputee, future energy expenditure is inversely proportional to the residual limb length (46). The surgical stabilization of long bone fractures with external fixation should be performed after hemostasis and decontamination.

Corresponding In-Theater Critical Care

The focus of initial critical care is to restore the physiologic state so that the patient is ready for repeated operative interventions and the series of transfers back to the United States for definitive care. Hemodynamics, ventilation, coagulation status, and ongoing resuscitation are addressed along with a more comprehensive tertiary survey and adjunctive measures, such as CT scans, in order to catalogue the extent of all injuries that may have been previously overlooked. The patient is thoroughly resuscitated with correction of any coagulopathies in anticipation of secondary surgical procedures. The resuscitation of these complex casualties is a continuum that begins in the trauma bay and persists unabated as the patient moves back and forth from the OR to the ICU. It is during this phase of resuscitation and ongoing surgical debridement that these patients manifest an inflammatory response to injury and resuscitation with such objective signs as fever, tachycardia, and elevated laboratory values, which may be consistent with a systemic inflammatory response syndrome (SIRS). This response may be prolonged and depend upon the extent of the initial injury, interventions given, and the patient's response to the injury and interventions.

Secondary Surgical Procedures

Upon adequate ICU stabilization, these complex wounding patterns require a series of repeat surgical debridements. This is attributable to the evolution of tissue necrosis in high-energy combat blast injuries and to the expeditious lifesaving manner of the index surgical procedure that may not haven adequately addressed all of the injury patterns. Secondary procedures may be initiated at downrange medical treatment centers or temporarily delayed until transport to upper levels within the current medevac system. By this time, the majority of lifethreatening hemorrhage has been stabilized and longer operative interventions may be undertaken with the goal of preventing localized or systemic infection.

Surgical debridement with irrigation is the essential secondary procedure. At this time, all large and small wounds should be revisited using a meticulous and systematic approach to remove all infected or non-viable tissue. Revision amputations may be necessary with a goal of maintaining any and all healthy soft tissue flaps for potential later coverage procedures. Temporary noncritical, small fracture stabilization is addressed at this time with the use of external or Kirschner wire fixation or simple reduction and splinting procedures. In the case of previous fecal diversion performed for open pelvic injury or perineal blast wounds, maturation of the colostomy may be performed with careful consideration of future orthopaedic surgical incisions.

Numerous studies have shown the value of delayed primary closure for war wounds; a complex cascade of bio-inflammatory cytokines and polymicrobial infections tend to create unique soft tissue challenges (49-51). The optimal early phase combat wound dressing has not been clearly established. Negative pressure wound therapy has been advocated for high-energy civilian and combat-related wounds, even open pelvic injuries (50,51). The use of an antibiotic bead pouch is also an effective dressing that may provide better antimicrobial outcomes than negative pressure dressings (52,53). Other options to be considered in this population are the use of Dakin's solution

and wet-to-dry dressings. No matter which dressing is selected, the value of a thorough surgical debridement and irrigation cannot be overstated. Finally, communication of accomplished procedures and future surgical needs should be transmitted to treating surgical teams uprange.

Medevac Transport and Uprange Definitive Care

Expedited evacuation of casualties to progressively higher levels of care is the standard medical doctrine employed to support the current combat operations in Iraq and Afghanistan (54). This process should be viewed as a continuum of care during which resuscitation and operative debridements concentrate on definitive control of the injuries. This necessitates frequent "hand-offs" of care to serial uprange medical teams with eventual strategic evacuation out of the combat theater to Landstuhl Regional Medical Center (LRMC) in Germany, the sole Level 4 facility in the combat medical system. These patients are then routinely transported back to the continental United States for definitive care. A weekly video teleconference, as well as integrated distribution of the medical record, helps to ensure that patient care is not disrupted during these frequent movements. Centers of excellence, representing the highest levels of care, provide final combat casualty treatment at US-based facilities such as Walter Reed National Military Medical Center and Brooke Army Medical Center. Definitive care is extensive and requires a multidisciplinary format, which is discussed in detail in subsequent articles within this issue.

Conclusion

The care of complex dismounted IED blast injuries is among the most difficult and challenging for both orthopedic and general surgeons. As described in this review, a coordinated effort at every level of care is required for index survival and long-term reconstruction. Despite the devastating nature of these injuries, successful outcomes are achievable both in the short and long term. Surgeons during the Vietnam War faced less frequent but similar bilateral LE amputation injury patterns (25). Despite limited reconstructive options and rudimentary prostheses at that time, these historic patients had acceptable longterm outcomes. With modern advances in combat casualty care and prosthetics, we expect similar results with respect to the complex dismounted IED blast injury even despite its more destructive nature. Long-term followup is necessary to establish the overall morbidity and mortality of this injury pattern, including final measurable outcomes of disability and the extent of functional recovery and lifelong prosthetic needs. As with previous wars, the medical

experience and lessons learned from the care of these complex battlefield injuries will continue benefit future military and civilian patient encounters.

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