The Role of Surgery in Building Resilience to Blast Attacks

Vivian C. McAlister
Blast attacks are the commonest form of terrorist attack on civilians. Blast often causes injury from industrial accidents. Blast injury is the most common cause of injury and death in modern combat. A recent review of Canadian fatal casualties in Afghanistan found 81% to have been caused by blast, almost four times the number killed by gun shot wounds. Improvised explosive devices (IED) caused 78% of the blasts with another 20% being due to rocket propelled grenades (RPG). The purpose of this review is to outline the mechanisms of injury, to define the surgical response and to understand the implications of recent surgical experience in Afghanistan.

The mechanism of blast injuries may be categorized in several ways according to the forces developed in each phase of the blast; the environment in which the blast occurs; the propellant or the content of the bomb. Conventional categorization divides the mechanisms of injury into phases of energy dissipation. In the first phase primary injuries are caused by pressures created by the blast itself, known as overpressures. The body is remarkably resilient to overpressures and its response is unpredictable. Massive overpressures, which cause amputation of extremities and spine injuries, are usually fatal. A hierarchy of sensitivity to overpressures appears to exist experimentally so that tympanic membrane rupture occurs at lower pressures than injury to the hollow air-filled organs such the lung or the gastrointestinal tract. Other organs, including the liver, spleen and even the brain, are surprisingly resilient to primary blast injury. Secondary injury is due to fragments, propelled by strong blast winds behind the pressure front, causing penetrating or blunt injury depending on the size and velocity of the fragment. Phase 3 (Tertiary) injury is caused by the movement of the victim by the force of the blast resulting in injuries similar to a car crash. Injury to the victim from other elements of the explosion such as heat, light or toxic gasses is considered to be Phase 4 (Quaternary). Recently a fifth phase (Quinary) has been added to include injury from contaminants such as bacteria, radiation and chemicals which can persist long after initial recovery.

The probability of sustaining a particular type of injury is related to the distance from the centre of the explosion. At the epicentre of the blast, thermal injuries occur, with blast injuries just outside this area and ballistic injuries at the outer limits. Energy dissipates rapidly so that injury may be devastating to the target and minor to those just a little away from the epicentre. This effect is seen in IED attacks on dismounted patrols in Afghanistan. The target of the IED is often severely injured while soldiers on either side in the patrol suffer superficial injury. The environment in which an explosion occurs has a profound impact on the injuries sustained. While blast energy dissipates rapidly in an open environment, blast in enclosed spaces may allow for magnification of energy through the reflection of waves by containing walls. An IED attack on dismounted patrols may only seriously injure one person but a suicide bomber may kill and injure large numbers of people if the bomb is detonated inside a bus or a building. Similarly detonation of a grenade inside an armoured vehicle, once the RPG has penetrated, will injure all the occupants. In enclosed spaces the potential for secondary blast injury is greater than in the open not only because of reflection of high energy waves but also because surrounding objects may become secondary ballistic material and because of the potential for inhalational injury.

Blasts may be categorized according to the propellant or the content of the bomb. Energy generation is considerably greater with high grade explosives compared to conventional explosives. Improvised explosives, using old shells, fuel or fertilizer, have even less power. However the enemy understands these variations.
IEDs are built and shaped so that impact on the victim is less variable than the ability of the propellant to
general force. Increasing protection of vehicles has changed the character of recent warfare. Anti-RPG devices
have reduced the number of attacks with this weapon. Double V mine resistant anti-ballistic hulls have forced
the enemy to use larger IEDs to successfully attack mounted patrols. Remote operated aerial observation has
made deployment of large IEDs more difficult and hazardous. Evidence from casualties presenting to hospital
suggest a change in focus of attacks from mounted to dismounted patrols starting in Spring 2010.

The content of bombs determine the type, intensity and the duration of injuries sustained by victims.
Incorporation of incendiary materials such as white phosphorous into IEDs alters the injury pattern. Residual
material may burn and ulcerate tissue. The impact varies depending on the site, being lethal new great vessels,
having lasting effects in the lungs and extending wounds on skin and subcutaneous tissue. Suicide IEDs result
in biological ballistic material that may expose the victim to infections such as HIV or Hepatitis viruses. Anti-
personnel IED injuries are very frequently contaminated by soil and subsequent infection with antibiotic
resistant soil organisms is common.  

Therefore blasts cause the full spectrum of illness and injuries seen by trauma surgical teams. The body is
surprisingly resilient to primary blast injury. Despite the hierarchy of sensitivity to pressure of different organs
and parts of the body seen experimentally, this information has had little impact clinically. For instance,
absence of tympanic membrane rupture does not mean that lung or gastrointestinal injury is also absent. Despite
this fact, blasts in particular conflicts produce an injury profile that is quickly recognized by
experienced trauma teams, who use the knowledge to expedite care.

Surgical care for blast injured soldiers starts in the field. Advances in buddy care through the Tactical Combat
Casualty Care (TCCC) program and development of the range of procedures provided by unit medical
technicians have increased survival and successful transfer of patients to forward surgical facilities. Reviews
of fatalities and of survivors in recent conflicts have quickly modified these programs to maximize success. Rapid evacuation is required to capitalize on the gains made by the first responders. It is unlikely that
 provision of surgical or other medical specialist skills at the site of injury, or on the evacuation, would
 improve the outcome. The receiving medical facility must be adequately resourced and have rehearsed
 reception of large numbers of injured patients. Principles of triage and damage control resuscitation have been
developed for mass casualty incidents but are applicable if only one casualty arrives. Patients in trauma bays
are treated with the same primary survey – resuscitation drill regardless of the extent of injury so as not to
miss occult but consequential injuries. These drills are based on the Advanced Trauma Life Support protocol
used in civilian trauma, which are modified to account for the hemorrhagic nature of combat casualties. Early
administration of blood, plasma and platelets has reduced the risk of irreversible traumatic shock. Clinical
examination is augmented by portable X-ray, rapid focused ultrasound and CT scanning.

The Joint Theater Trauma Registry (JTTR) director's annual report in June 2011 registered 7809 admissions in
the previous year to combat surgical facilities in Afghanistan and Iraq. Of 617 seriously injured patients, 277
had suffered blast injuries. IEDs accounted for 203 patients, 73% of the blast injuries reported. The vast
majority of admissions were received by air medevac but a significant number arrived by road ambulance as
well. Only 1% of ISAF / OEF soldiers were in shock (defined as base deficit > 5) on arrival whereas 7.4% of
local patients were in shock. Blood transfusion was given to 780 coalition casualties and to 926 local
nationals. Emphasis was placed on use of 'fresher' blood in shocked patients and on the use of adequate
volumes of matching plasma and platelets. Massive transfusion was given to 399 patients. Longterm survival
rates of 95 to 100% were recorded for coalition members receiving massive transfusion in each quarter of the
year.

The dismounted target of an IED who either triggers the device or is remotely targeted has a completely
different injury to those next to him or her. Bystanders may suffer from penetrating wounds from ballistic
The Role of Surgery in Building Resilience to Blast Attacks

debris. The target suffers devastating injury with at least one limb amputated. It was our impression after several tours that the injury profile for these patients was changing for the worse. The JTTR reports equal numbers of mounted versus dismounted IED attacks for 2009 averaging less than 5 per month each. Beginning in February 2010 the rate of dismounted attacks increased by over 300% to over 15 per month while mounted attacks declined. With Cdr Joseph Taddeo, US Navy, I examined the injury profile of 100 consecutive dismounted IED victims, who had suffered at least one extremity amputation, and were treated at the Role 3 Multinational Medical Unit in Kandahar Air Field between January 2010 and July 2011. Single, double, triple and quadruple amputations were recorded in 43, 40, 3 and 3 patients respectively. Lower extremity amputations included 4 at the foot, 73 below the knee, 75 above the knee, 2 hip disarticulations and 15 unspecified lower limb amputations. Upper limb amputations included 4 at one or more digits, 10 hands, 9 below elbow, 7 above elbow and 5 unspecified. Extremities not amputated were at risk of complex soft tissue – bone injury. A particular injury was seen at the elbow where the joint was blown away but the soft tissue of the ante-cubital fossa was preserved, providing circulation to the hand. Associated injuries included 34 severe injuries to the perineal-genital-gluteal region, 33 severe soft tissue injuries, 11 pelvic fractures and 11 eye injuries. In this group of 100 severely injured patients, associated injuries were reported in less than 5 each of the head, spine, chest, abdomen or tympanic membrane. Intraperitoneal injuries only occurred in 4 patients who were local nationals without body armour, all of whom died. Soft tissue injuries involved the deep dispersal of silica type soil and quarry grade stones along areas of anatomical cleavage. Patients with pelvic injuries required massive blood transfusions. All the patients required multiple operations for irrigation and debridement. Despite this strategy and the liberal use of antibiotics wound contamination with soil organisms such as Acinetobacter baumannii was commonly discovered later down the evacuation chain. The overall survival rate was 82%, all of whom will require extensive rehabilitation and support.

From this data, we were able to define an injury profile for the dismounted IED attack to include the following: bilateral lower extremity amputations with severe soft tissue injury extending into gluteal muscles; severe perineal – genital laceration extending into ischio-rectal fossa; mangled or amputated upper extremity; severe soil contamination of wounds extending deeply, well beyond the point of entry. The surgical evidence points to the use of a shaped charge packed with stones and soil, designed to travel up between the victims legs to disrupt the perineum. Body armour prevents torso injury. Flexion of the elbow to carry the weapon exposes it to the blast but protecting the neurovascular elements in the antecubital soft tissue.

CONCLUSION

Blasts can result in a wide spectrum of injuries. Injury profiles can be developed for particular weapons used in particular environments. Counter IED measures have induced changes in enemy tactics which are reflected in changing patterns of injuries seen in combat hospitals. The injury profile of dismounted IED victims suggest a conscious effort to not only remove the soldier from the fight but to inflict the maximum amount of pain and suffering without causing death. Research goals in the short-term should include ways to ameliorate injury to pelvic–perineal region including use of pelvic binders in the field, surgical strategies to rapidly control pelvic hemorrhage, medical strategies to address soil organism contamination and personal protective equipment design. Longer term research goals should include limb replacement technology and foot wear development to attenuate energy transferred from ground to foot.

REFERENCES


