Mechanisms of Injury in Wartime

Cheryl Lehman, PhD RN BC CRRN-A

KEY WORDS

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A significant number of wounded servicemembers are returning from the conflicts in Iraq and Afghanistan. As the U.S. government finds itself with more wounded servicemembers than its systems can handle, the wounded are beginning to use private rehabilitation facilities. Mechanisms of injury in war are unlike those of most injuries encountered in civilian life. Rehabilitation nurses in both military and private rehabilitation facilities can benefit from learning about the mechanisms of injury in war to better help their patients and anticipate potential and hidden complications. This article reviews the mechanisms of injury in Operation Enduring Freedom in Afghanistan and Operation Iraqi Freedom, the unique characteristics of military personnel, and the implications for rehabilitation nurses.

Operations Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) are producing injuries in different patterns from previous wars. Not only are the modes of injury different, but the servicemembers who are injured have different characteristics than those in other wars, potentially resulting in different patterns of rehabilitation and recovery. The modes of injury in these wars include not only occupational injury and injury from guns and missiles but also injury from improvised explosive devices (IEDs), roadside bombs, and suicide bombers. Servicemembers now include older adults, women, and physically and mentally fatigued personnel who have had multiple deployments. This article reviews the common mechanisms of injury in these wars, the characteristics of the service personnel, and the implications for rehabilitation nurses.

Background

More than 24,000 injuries to American servicemembers have been attributed to the military action in Iraq as of March 24, 2007 (U.S. Department of Defense, 2007b). More than 96% of these injuries are caused by weapons such as bombs and explosive devices (71% of weaponry totals), artillery and mortars (11.5%), and gunshots (8.2%; U.S. Department of Defense, 2007a). Iraqi fighters have embraced the use of IEDs—which are known for causing grave injury and death—resulting in unanticipated numbers of servicemembers returning with limb amputation or head injury. Servicemembers injured in nonhostile incidents are not included in these numbers. Although the exact statistics are not known, it is thought that more than 200,000 servicemembers have been treated in the Veterans Affairs (VA) system as a result of OEF/OIF (Stephen, 2007).

The ratio of wounded-to-killed servicemembers is different in this war than in past wars. In World War I, for example, there were 1.8 wounded troops for every 1 killed. These numbers changed to 1.6:1 in World War II, 2.8:1 in Korea, 2.6:1 in Vietnam, 1.2:1 in the first Gulf War, and 16:1 in OIF (Information Clearing House, 2007). Improved armor, superior field medical care, the proximity of the medical care and field hospitals, and the proximity of the Army hospital at Landstuhl, Germany, have been credited with the large number of wounded survivors. However, the vast numbers of wounded troops affect not only military and VA hospitals and rehabilitation centers but also facilities in other settings because the U.S. government has contracts with local and state rehabilitation facilities.

Servicemember Characteristics

This is the first U.S. war conducted with an all-volunteer military. Military staffing shortages have changed the profile of deployed servicemembers. Repeated deployments into the war zones have been more frequent and last longer (Breslau, 2006). Rest time between deployments has been reduced, resulting in less time for recuperating and training (Alvarez, 2007). Injured troops are being redeployed into Iraq, which is an unusual practice (Murray, 2007). Older troops, some already retired, are being deployed (Rizzo, 2005). Women are being deployed in increasing numbers, and because of the characteristics of the field of battle, they are more likely to find themselves in the combat zone (Simon, 2005). Reservists who did not expect to be deployed have also been sent into battle.

Older reserve troops, in particular, are finding deployment difficult. "Long shifts lifting cargo and climbing stairs; the stress of a daily commute on roads insurgents were known to attack; the lack of sleep from living with others in a tent" have resulted in medical problems for many servicemembers (Rizzo, 2005). As many as 40% of the troops in Iraq are part-time soldiers (Rizzo). These troops are older. The average age of reservists is 33 and one-quarter of all reservists are 40

and older. More troops arrive at the Army hospital in Landstuhl with noncombat injuries than injuries from battle. The primary reasons for transport to Landstuhl are chest pain, back pain, and hernias. These figures are easy to explain; according to Colonel Randolph Modlin, chief of cardiology at Landstuhl: "We've never gone to war with guys as old as this before" (Rizzo).

Modes of Injury: Occupational

Although it is logical to assume that all troops are at risk for injury from warfare, it is easy to forget that occupational injuries can be a major source of injury for this population. Every job in the military carries some risk of occupational injury. For instance, all branches of the military maintain and use heavy equipment, including helicopters, tanks, airplanes, ships, submarines, trucks, and even construction equipment such as end-loaders and cranes. Risk is inherent when using heavy equipment; crashes, fuel spills, fires, electrocution, malfunction, and human error can cause severe injuries and deaths. Personnel who lift, move, and carry heavy loads are at risk for back injuries and falls. Even the cooks are at risk from hot grease and fires.

Deployment to foreign soil carries other risks. For example, there is a real danger of contracting an infection from unfamiliar bacteria and other agents, and infection can delay wound healing. Exposure to toxic chemicals can cause inhalation injuries and burns. In Iraq, extremes of heat and cold can cause health problems such as sunburn and heat stroke. Sand storms can also cause injury. Military training entails its own risks of muscle strains, sprains, and orthopedic problems. And another hazard often overlooked during wartime is recreational injury. Football games and other sports can also result in sprains, strains, and fractures.

In fiscal year 2005, Army accidents service-wide resulted in 306 soldier deaths, 141 deaths in privately owned vehicles, 34 aviation deaths, 28 deaths in off-duty nonprivately owned vehicles, and a payout of more than $175 million in worker's compensation claims for work-related accidents (U.S. Army, 2007).

Occupational injuries seen in civilian life are being seen in Iraq and Afghanistan. Although the causes may be nonhostile, they can still result in life-altering injuries such as those of the spinal cord or head. The exact numbers have not been publicized, but the officially released figures (as of February 3, 2007) reported that the 6,991 injuries requiring medical air transport were attributable to nonhostile causes in OIF.

Modes of Injury: Warfare

The field of combat is unique in OEF/OIF. OIF in particular is being conducted in a mainly urban setting, which changes the methods of warfare. House-to-house searches are common, as is rooftop surveillance. Bombs are transported in cars and buses and are strapped to bodies. IEDs are planted along routes of travel. Small arms play a significant role in the outcome of urban battles, and rocket-propelled grenades are a common and effective weapon. Hit-and-run tactics by small groups are often used. The urban guerrilla often uses homemade weapons, including chemical weapons. Servicemembers' equipment load must be reduced substantially because urban warfare requires great agility and stamina (Staten, 2003).

Blast Injury

The media are calling amputation and closed-head injury the signature wounds of this war. The cause of each of these is likely to be blast injury. As mentioned earlier, bombs and explosives are the cause of more than 70% of weaponry injuries.

The 1983 bombing of the U.S. Marine barracks illustrates the damaging power of blasts. The bombing resulted in 234 immediate deaths and at least 122 injured survivors. Of the dead, 167 had evidence of head injury. There was a 59% rate of head injury and a 70% fatality rate from head injury in this incident (Defense and Veterans Brain Injury Center [DVBIC], n.d.). Early data from OIF are similar. The DVBIC at Walter Reed Hospital screened 155 patients in 2003 who had returned from Iraq and were suspected to be at risk for brain injury. Sixty-two percent were identified as having a new brain injury. Sixty-one percent of those involved in a blast had sustained brain injury (DVBIC).

Blast injuries are caused by rocket-propelled grenades, IEDs, and land mines (DVBIC, n.d.). Blast injuries themselves result from the complex pressure waves during an explosion. Injuries are classified

Key Practice Points

1. As the U.S. government finds itself with more wounded servicemembers than its systems can handle, the wounded are beginning to access private rehabilitation facilities.
2. Operations Enduring Freedom and Iraqi Freedom are producing injuries in different patterns from previous wars.
3. It should be standard practice to assess all wounded servicemembers for posttraumatic stress disorder.
4. During this war, military families have endured constant stress that has been fostered by nearly continuous media coverage of the war and will require support, counseling, training, and guidance from the entire rehabilitation team throughout the rehabilitation process.

as primary, secondary, tertiary, and quaternary and miscellaneous, depending on the stage of the blast in which they occur.

Primary Blast Injury. There are several stages to a blast. First, there is a wave of overpressurization, in which the air pressure is instantaneously higher than atmospheric pressure (DVBIC, n.d.). Blast overpressure "forms from the compression of air in front of a blast wave which heats and accelerates the movement of air molecules" (Wallace, 2006). This phenomenon is called the positive phase of the blast wave (Wallace). The ears, lungs, gastrointestinal tract, cardiovascular system, brain, and spinal cord are especially susceptible to damage from the primary blast wave.

Those closest to the blast are at highest risk (DVBIC, n.d.), although individuals next to each other during a blast may experience radically different outcomes depending on their exposure to the blast waves (Warden, 2006). Severe primary blast injuries are rarely seen in survivors because those closest to the blast are likely to die from fragments energized by the blast. It is theorized that portions of the brain swell and instantly decompress during this stage, causing defects at the cellular level throughout the brain (Mason, 2007). The primary blast injury can also fracture bones and may be responsible for limb avulsions if the stress waves are of high intensity (Covey, 2002).

The primary blast wave damages tissue in four ways: spalling, implosion, acceleration/deceleration, and pressure differentials. Spalling occurs when particles from a more dense fluid are forcibly pushed through a less dense fluid at the interface of two different media. Implosion implies a contraction of gas pockets that occur as a blast wave progresses through tissue. These gas pockets then reexpand, causing injury from multiple miniature internal explosions. Acceleration/deceleration injury occurs when movement of the body and internal organs in one direction is initiated from the blast, and the movement is abruptly changed when the body contacts a blast wave from a different direction or when the body meets a solid object. Pressure differentials between the outer surface of the body and the internal organs during a blast wave can cause internal injury (Covey, 2002).

Covey (2002) reported a study by Cernak in which survivors of explosive blasts were found to have elevations in plasma arachidonic acid metabolites thromboxane A, prostacyclin, and sulfidopeptide leukotrienes, suggesting that the transmission of the blast wave through the body can cause extensive, measurable pathophysiologic alterations. Hull and Cooper (1996) found that limb amputation due to the primary blast wave occurs at a blast wave-induced fracture site rather than at a joint. Primary blast wave injuries include not only traumatic brain injury and amputation but also tympanic membrane rupture, perforation of the globe of the eye, abdominal hemorrhage, and pulmonary barotraumas (Wallace, 2006).

Secondary Blast Injury. The overpressurization wave is followed by the negative phase of the blast: a vacuum effect as the pressure drops below ambient air pressure. This generates a blast wind that can propel people and objects and that may be as damaging as the original explosion (Covey, 2002).

Secondary blast injuries result from objects "energized by the explosion to become projectile" (Covey, p. 1221). These injuries most often involve the musculoskeletal system and therefore are the cause of severe tissue injury and amputation. Blast fragments can carry environmental debris into the wound, setting the wounded person up for infection and nonhealing. The use of modern body armor tends to protect the chest and abdomen from secondary blast injury, but there has been a relative increase in fragment wounds to extremities not covered by armor (Covey). Secondary blast injuries may include eye penetration and open-brain injury (Wallace, 2006).

Tertiary and Quaternary Blast Injury. Tertiary blast injuries result when the victim is thrown against the ground or injured by the collapse of a structure. Fractures, crush injuries, amputations, and severe soft tissue lacerations and contusions can result. Other blast injuries include dust inhalation and thermal burns from the bomb itself or from a resultant fire.

Results of Blast Injuries. Results of blast injuries can be more complicated than isolated amputation or brain injury. For example, the American Speech-Language-Hearing Association (2006) has identified the following impairments that may result from blast injuries:

- cognitive communication impairments
- swallowing impairments
- aphasia
- motor speech impairment
- oral and facial burns or other traumas that affect communication
- tracheostomy and mechanical ventilation affecting communication
- hearing loss.

Of the 175 blast-injured patients seen at the Army Audiology and Speech Center at Walter Reed Army Medical Center between 2003 and 2005, 66% were referred for swallowing evaluations, 56% for speech/language deficits, 30% for tracheostomies necessitating speaking valves, and 29% for voice disorders. During the same time period audiologists at Walter Reed saw 257 blast-injured patients, of whom 64% had ear injury and hearing loss. Fifty-two percent

of these patients had sensorineural loss, 21% had conductive hearing loss, and 27% had mixed hearing loss. Twenty-five percent of those with hearing loss had bilateral loss, 34% were unilateral left, and 34% were unilateral right. Thirty-two percent of the blast-injured patients had tympanic membrane perforation (Chandler, 2006).

What remains unknown is the result of repeated exposure to blasts when each exposure does not necessitate evacuation from the field of battle (Warden, 2006). A comparison of patients with blast and nonblast closed-head injuries at Walter Reed found that those injured in a blast were more likely to have had a skull fracture, seizures, and lower-extremity amputation than those with a closed injury who were not injured in a blast. Those injured in a blast were also more likely to have symptoms of acute stress reaction or posttraumatic stress disorder (PTSD). No differences were found between the groups in postconcussive symptoms (Warden).

Small Arms Injuries

Small arms include pistols, rifles, and machine guns. They are used by individual soldiers with the primary goal of injuring or killing enemy personnel. They fire solid projectiles that have diameters less than 20 mm. Small arms are effective at differing distances, depending on the type of gun, and different types of bullets have different purposes. For example, the most common type of bullet, ball ammunition, is meant to injure or kill. The tracer bullet contains chemicals that show the track of the bullet. The armor-piercing bullet is meant to penetrate vehicles. The incendiary bullet is meant to ignite combustibles, such as gasoline. Although each type of bullet has a different purpose, there is no evidence that the type of bullet causes unusual problems that require special treatment (Bellamy & Zajtchuk, 1991).

The bullet's construction determines the type of wound it will cause. According to the Hague Declaration of 1899, bullets meant for military use must be completely covered by a metal jacket, the purpose of which is to prevent severe tissue damage. Even so, manufacturers have designed military ammunition that meets the specifications of the declaration while attaining the wounding effects of hollow-point or soft-nosed ammunition. Such fragmenting bullets can cause tissue damage equivalent to that of a hollow-point round, which extensively damages tissue as it passes through the body. Bullets that break up as they pass through tissue are much more injurious than bullets that remain intact (Bellamy & Zajtchuk, 1991).

The typical round of ammunition consists of two parts: the bullet and the cartridge. The cartridge contains the gunpowder and primer, and the bullet is inserted into the cartridge during manufacture. The diameter of the bullet is called the caliber and is usually measured in millimeters. A 5.56-x-45-mm round would measure 5.56 mm in diameter and 45 mm in length. Larger cartridges have higher bullet velocity and better range. They also weigh more, making smaller, slower rounds meant for smaller guns more useful to foot soldiers who must carry them in battle (Bellamy & Zajtchuk, 1991).

The purpose of bullets is to disrupt human tissue. Different bullets have different, often identifiable injury patterns. The blast effect of a bullet is the zone of damaged tissue around the wound that is caused by the bullet itself and is determined by the size and velocity of the bullet. The wounding patterns of hollow-point and soft-nose ammunition are different and more destructive than those of nondeforming bullets. Bullets from high-velocity rifles usually cause less soft-tissue destruction as they pass through the body (Bellamy & Zajtchuk, 1991).

Modern combat in urban settings can be very lethal. Data from Israel indicate that the most common cause of injury in West Bank operations is from bullets, with a 24% mortality rate of those injured severely enough to be hospitalized. Chest injuries accounted for 67% of the moderate, severe, and lethal injuries, with 73% of those with chest injuries dying. Data about combat from past conflicts in Lebanon show an increase in the proportion of bullet wounds from 13% to 48% and a decrease in shrapnel wounds from 74% to 17% of all injuries (Champion, Bellamy, Roberts, & Leppaniemi, 2003). In the 2003 Gulf conflict, 37% of casualties treated at a British field hospital had gunshot wounds. Of 29 patients with gunshot wounds, 23 had extremity wounds, 5 had head and neck wounds, 4 had abdominal wounds, and 3 had chest wounds (patients could have more than one wound each). The percentage of patients seen with gunshot wounds was higher than during the 1991 Gulf War, leading the authors to believe that the findings reflected a lower intensity of bombing and more fighting in the urban landscape (Hinsley, Rosell, Rowlands, & Clasper, 2005).

Deaths from gunshot wounds total only approximately 5% of all deaths in OIF (U.S. Department of Defense, 2006). Tampa Polytrauma Rehabilitation Center reported that approximately 9.3% of its OIF/OEF patients with a combat-related injury had a gunshot wound (Walker, 2007).

Patterns of Hospitalization

From March 19, 2003, to May 19, 2006, 26,802 people were medically evacuated from the field of battle in OIF, 20% for battle injuries, 17% for nonbattle injuries, and 64% for disease-related problems. In contrast, between October 27, 2001, and February 27,

2006, 4,619 people were evacuated from OEF, 9% for battle injuries, 18% for nonbattle injuries, and 73% for disease-related problems (U.S. Department of Defense, 2007b). The majority of injuries treated at Walter Reed Medical Center in 2006 were upper extremity (31%), head and neck (28.7%), and lower extremity (26.7%; Serving Those Who Serve, 2007).

Air transport from the field of battle causes its own problems for the critically injured because of changes in partial pressure oxygen, temperature, and humidity and fatigue (Liolios, 2004). Altitude challenges the hemostasis of patients in flight. The higher the altitude, the lower the barometric pressure, which causes any abnormally trapped air in the body to expand. Decreased barometric pressure can cause problems for patients with respiratory or cardiac difficulties, necessitating supplemental oxygen. Other stressors of flight include noise, gravitational and acceleration forces, and vibration of the aircraft (Boivin, 2005).

Infection

First detected as a pattern in 2003, drug-resistant *Acinetobacter baumannii–calcoaceticus* complex (ABC) wound infections are common among servicemembers who are wounded in Iraq. The bacteria are normally found in Turkey, Taiwan, and Vietnam, and it is thought that the infections come from the field hospitals themselves. Cleaning field hospitals thoroughly is extremely difficult, and the influx of multiple wounded personnel at a single time challenges infection-control techniques. Other common battle-acquired infections include *Escherichia coli* and *Pseudomonas*.

IEDs and other weapons often are coated with animal feces to increase the chance of injuring the enemy. Infections are more common in blast injuries, soft tissue injuries, and personnel with more than three wounds, limb loss, abdominal trauma, and a high injury severity score (News-Medical.net, 2007; Peterson et al., 2007).

Psychological Injury

PTSD is another injury from war. Research has shown that the more a servicemember is exposed to combat experiences and the more intense those experiences are, the more likely it is that the servicemember will experience chronic PTSD (Litz, n.d.). PTSD can be frightening for the servicemember and the family. People with PTSD often isolate themselves from family members. The anxiety and irritability demonstrated by the person with PTSD can negatively affect the family. People with PTSD often are more violent, and their children are at higher risk for behavioral, academic, and interpersonal problems (Price, n.d.). PTSD is often a hidden illness, not easily diagnosed and often missed by healthcare providers.

The American Psychological Association (APA, 2007) released a report to call attention to the mental health needs of military personnel deployed in support of OEF and OIF and their families. The report cites studies showing that a growing number of military families and servicemembers are reporting emotional problems resulting from deployment. Although 30% of all soldiers meet the criteria for mental disorders and are eligible for services, less than half of them seek help. Even so, mental health service provision is stretched thin. There is a 40% vacancy for psychologists in military service. Long waiting lists, limited clinic hours, and hard-to-reach locations make it difficult for military families to obtain help. The APA report recommends ensuring that treatment is available to servicemembers and their families throughout the deployment cycle, with a special focus on PTSD and traumatic brain injury.

Implications for Rehabilitation Nurses

Servicemembers are sustaining unique injuries and complications in OEF and OIF. Rehabilitation nurses across the United States are more likely to care for this population as wounded servicemembers return to the United States and receive both military and private care. Knowledge of the mechanisms of injury will help the rehabilitation nurse more fully assess the patient for not only obvious results of injury but also hidden injury and potential complications.

Acute injuries and early complications are likely to have been managed by the time patients reach the rehabilitation setting. Complications that may be anticipated in the rehabilitation setting include pain, impaired function from injury and scarring, delayed onset of infection, movement of bullets or explosive fragments that were left in the body, occult injuries such as subtle traumatic brain injury, and psychological damage such as PTSD.

A bullet can be expected to leave damage along its entire path through the body. Some bullets tumble inside the body and may leave greater damage inside than what is visible outside. Although there may be simple entry and exit wounds, multiple organs could have been damaged and bones and tissues nicked as the bullet traveled along its path. Delayed presentation of internal injury is certainly possible. The rehabilitation nurse should make it a priority to determine the length of time since the wound's infliction, the path of the projectile, the known damage to tissues, and the acute care treatment. Assessing the patient (specific to injury by bullet) includes wound-site and healing status, functional status, pain profile,

and signs and symptoms of infection. The nurse must also ascertain history of exposure to blast injuries (whether the patient was wounded or not) so that screening for brain injury and hearing loss can be initiated if necessary.

Blast injuries are likely to leave not only visible damage but also blast-wave damage to internal organs, multiple fragments in the body, and a high chance of infection. Delayed presentation of internal injury is possible. As mentioned earlier, the effect of exposure to multiple blasts is unknown. Assessments in the rehabilitation setting should include a history of blast exposure (i.e., number of times), current wounds and healing status, functional status, and pain profile. Hearing should be tested, and in-depth screening for traumatic brain injury should always be completed. In conjunction with brain injury, swallowing function should be monitored. The risk of inhalation injury should not be ignored. People injured in blasts have a high likelihood of inhaling dust and toxins, with either immediate or delayed reactions.

It should be standard practice to assess all wounded servicemembers for PTSD. PTSD can affect rehabilitation and reintegration into the military, family, and societal communities. Community reintegration is an important outcome of any rehabilitation program. Certain populations are at high risk for failure to reintegrate into the community, including those with head injuries and psychiatric disabilities (Buchanan & Neal, 2002). Failure to succeed in community reintegration can lead to isolation, loss of social support, institutionalization, violence and abuse, and decline in health. People who experience psychological trauma, such as deployment to a war zone, and who return with or without physical trauma must go through a process of community reintegration as they adapt to changing social situations and evolving values. War veterans must confront the differences between who they were before deployment and who they are now as they adapt to the community.

Families must be included in the care and rehabilitation of the returning family member. These military families have had to cope with an unanticipated war, long and repeated deployments of their loved ones, uncertainty about their futures, issues of everyday life while their loved one was away, and now with a physically or mentally impaired spouse, parent, sibling, or child. Military families' stress is aggravated by nearly continuous media coverage of the war, and during rehabilitation they will need support, counseling, training, and guidance from the entire rehabilitation team.

The rehabilitation nurse has an important role to play in the rehabilitation of wounded servicemembers. Knowledge of the modes of injury and the anticipated complications can help nurses deliver expert care to those wounded in war and to their families, facilitating a successful community reentry.

According to the Associated Press (2007), "More than 800 [servicemembers] have lost an arm, a leg, fingers or toes. More than 100 are blind. Dozens need tubes and machines to keep them alive. Hundreds are disfigured by burns, and thousands have brain injuries and mangled minds. These are America's war wounded, a toll that has received less attention than the 3,500 troops killed in Iraq. Depending on how you count them, they number between 35,000 and 53,000. More of them are coming home, with injuries of a scope and magnitude the government did not predict and is now struggling to treat."

About the Author

Cheryl Lehman, PhD RN BC CRRN-A, is an associate professor in acute nursing care at the University of Texas Health Science Center–San Antonio, San Antonio, TX. Address correspondence to her at lehmanc@uthscsa.edu.

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