

Countering the Global Landmine Epidemic Epidemic Epidemic

...Through Basic Science Research

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Since their first use during the U.S. Civil War (Croll 1998), blast landmines have played a role in almost every armed conflict from the World Wars to the most recent limited skirmishes. Landmines are the epitome of the consummate soldier: always ready, never tiring. Mines are simple devices that can fabricate with little effort and from readily available materials. In Sri Lanka, numerous news releases covering the conflict mention a "Johnny mine" (Botsford 1997), which is a local term for an improvised explosive device. Manufactured mines can be inexpensive, costing as little as two dollars apiece. If mine laying operations ceased tomorrow, an estimated 100 million mines would remain in place throughout the world (United Nations 1994).

Burden

Landmine injuries have reached epidemic proportions in the Third World, affecting both combatants and civilians. From 1980-1993, the incidence of landmine related injuries doubled, resulting in an

estimated 2,000 deaths or injuries per month (Rutherford 1997). Designed to maim rather than kill, landmine injuries can quickly overburden local medical services, creating shortages of medical supplies and lengthening the wait for treatment. Landmine survivors often require more surgical procedures than other war injuries, longer recovery times and their injuries rapidly deplete the limited blood supplies. Even with international assistance, many countries' emergency services are quickly overwhelmed, further escalating the morbidity and mortality rates for these and other injuries (Stewart 1999).

Landmines have a lasting effect on the indigenous population of affected countries in many aspects of daily life. By limiting access to agricultural areas, landmines may contribute to famine, forcing inhabitants to farm in mined areas, thus increasing the number of victims. For landmine amputees, the limited supply of adequate prosthetic devices can determine their level of dependence on others for support, further burdening the economy.

Personal Protective Equipment

While Personal Protective Equipment (PPE) will not be available to everyone in a mine-threat area due to the cost and sheer numbers involved, individuals responsible for landmine clearance operations require protection in case of accidental detonation. During the early 1900s, soldiers attempted to fabricate protective AP mine footwear using common materials, such as lumber and rope (Croll 1998). Later, in the early 1950s, the U.S. Marine Corps developed a six-inch sabot attachment for combat boots while the Army evaluated protective shanks in the 1960s (Fujinaka, E. S. & MacDonald, J. L. 1966).

Commercially produced mine-protective footwear is currently in use, and its effectiveness is being highly touted by the manufacturers. However, recent testing has shown these boots are inadequate in the prevention of severe injury, and further research is necessary to facilitate future development of effective mine-protective footwear.

Testing

Until recently, the evaluation of anti-mine footwear tests involved little more than material properties testing utilizing surrogate metal limbs or wooden forms. Evaluation of protective capability was determined by the boots' ability to remain intact. These test fixtures had little or no correlation to human physiology or the injury producing mechanisms. Past evaluations were unable to correlate test results with actual human injury.

In the 1990s, work conducted at the U.S. Army Natick Research, Development and Engineering

Center led to the development of new anti-mine footwear. Testing of this footwear began with laboratory material properties testing and ergonomic field trials during simulated clearance operations and then progressed into field trials utilizing surrogate metal limbs (Tijerino, & Hay 1999).

Evaluation

While these tests produced valuable information, the actual mechanism of injury was not fully understood. To better define the injury process, the U.S. Army Institute of Surgical Research, Extremity Trauma Study Branch (USAISR-ETSB), conducted field trials in collaboration with the Aberdeen Test Center (ATC) and the University of Virginia's Automotive Safety Laboratory (UVA) (Harris, et al. 1999). Based on years of research conducted by the automotive testing industry and the capabilities of ATC, cadaver testing was conducted to better understand the pathophysiology of a blast landmine injury and if protection is feasible.

The purposes of the study were the biomechanical evaluation of blast landmine injuries and to compare the medical outcomes to the various levels of protection provided by several types of commercially available footwear. Recognizing the inapplicability of injury scoring systems such as the International Committee of the Red Cross's (ICRC) wound scoring system (Coupland 1992) and other civilian studies (NISSA, MESS, MESSI) (Bonanni & Lucke 1993) (McNamara, Heckman, & Corley 1994) in assessing blast injury severity of the lower limb, the Mine Trauma Score (MTS) was developed (Harris, et al. 2000). The MTS was devised to compare the severity of landmine events under different test conditions without relying on any physiological parameters in order to apply it to the cadaver model. The vast majority of landmine injuries in the field require either transtibial or transfemoral amputations (Coupland 1991); however, the scope of the MTS includes values appropriate to lesser degrees of injury. This range of values allows for the evaluation of any protective effect provided by the footwear (Table 1). In addition, the MTS may allow for future retrospective studies of actual deminer injury records for validation purposes.

The MTS uses the following definitions of the injury criteria: I) Closed injury: injury of the lower extremity that does not violate (lacerate, tear) the skin. The potential infective sequelae of injury are minimal even with underlying fractures compromising functional outcome. II) Open contained injury: any

Mine Trauma Scoring System Table 1

Injury Assessment	MTS	Injury
No major injury	0	
Salvageable limb	1	Closed
	1A	Open contained
	1B	Open contaminated
Transtibial amputation	2	Closed
	2A	Open contained
	2B	Open contaminated
Transtibial/transfemoral	3	
Transfemoral	4	

lower extremity in which the skin is breached (lacerated, torn), but little evidence of contamination is present. An example would be a laceration to the skin of a foot contained within an intact boot. By avoiding the gross contamination usually associated with mine injury, this group may sustain fewer secondary infective complications. III) Open contaminated injury: any blast mine injury to the lower extremity in which the skin is not only violated but the exposed soft tissue is visibly contaminated. This contamination may be from the soil, footwear debris or landmine fragments. IV) Salvageable limb: an injury in which the severity does not render primary amputation inevitable. V) Transtibial/transfemoral: when the area of injury extends into the proximal third of the tibia and the severity makes it difficult to determine



Boot Designs
Photo c/o Rountree, Harris

the level of amputation required at the initial treatment. Even when the extent of soft tissue damage does not extend above the knee, there may be insufficient tibial length or adequate soft tissue to fit a workable prosthesis. In this circumstance, every attempt is made to keep the level of amputation transtibial for functional reasons; however, revision to a higher level may be required at a later stage. An MTS value of definition three represents this category of uncertainty of the final level of amputation.

Explosive blasts create smoke and other flying debris that obscure much of the event. The ATC has modified flash X-ray technology, incorporating pulsed emitters with a scintillating screen and a high-speed camera for Cineradiographic evaluation of the tests. Capable of recording eight images at a rate of up to 100 million frames per second, the first X-rays of a landmine event were obtained at 250 μ s intervals. These images have fostered a better understanding of explosive injury mechanisms.

Boot Strategies

Mine protective footwear strategies currently fall into three broad categories. The first is blast deflection that directs the blast away from the contacting limb (Wellco Blast boot alone). The second is stand-off, which uses elevation (BFR), or off-axis detonation (MedEng), to distance the involved limb from the mine blast. The third method involves blast attenuation that utilizes materials that decrease transmitted energy through a change in their physical state or attenuate the blast by destruction of the boot (Wellco Over boot). For the cadaver testing, four commercially available mine-protective boots were evaluated. A standard issue U.S. Army combat boot (Rosearch) was utilized as a control against which the boots were compared. Two single boot designs were evaluated: the BFR (Singapore) and the Wellco Blast boot (U.S.). In addition, two types of over-shoes were evaluated: the Wellco Over boot and the MedEng Spider boot (Canada) in multiple combinations with the single boots as inner boots.

Level of Protection

In reviewing the strategies incorporated with current protective footwear, no boot truly utilizes one independent method. The Wellco Blast boot and Over boot utilize both deflection and attenuation through an aluminum honeycomb; however, some direct contact standoff is achieved through the increased sole thickness or the combination of two boots. Use of the Over boot also contributes additional standoff and deflects some of the energy as the boot decouples from the inner boot. The MedEng Spider boot uses open-air standoff and off-axis detonation. The BFR boot couples an Aramid upper with insole to a thicker standard sole and was the only boot tested that employed simple standoff.

Medical Outcomes

There is an ongoing misconception among some soldiers and deminers that little or no foot protection is better. The belief seems to be that, without footwear, sacrificing the foot saves the leg. If this fact were the case, there would be strong argument for this technique. Field trials show that the unprotected, or minimally protected limb, incurs a possible transfemoral amputation even with the smallest landmine.

Medical studies have shown that as the level of amputation progresses above the knee, the increased energy expenditure for walking changes from 15 per-



Field trials show that the unprotected limb may mean transfemoral amputations.

Photo c/o Rountree, Harris.

cent to 40 percent with a prosthesis (Waters *et al.* 1976). Surgical amputation of the limb does not always constitute a failure of the protection or the medical care. Any protection that can reduce the number of transfemoral amputations is an improvement for the mine trauma victim.

Current footwear does not prevent severe injury but can provide a reduction in injury severity, especially with smaller charge weights. With the more effective boot combinations, injuries can be reduced from open contaminated wounds, which would require a possible transfemoral amputation, to a closed injury, allowing for a transtibial amputation or possible surgical reconstruction. Reduction in the potential infection rate and decrease in the number of transfemoral amputations constitutes a significant medical outcome improvement.

The study suggested that boots consisting of sturdier construction or materials, such as the Blast boot and BFR boot, seem to reduce soft tissue insult when used in conjunction with an Over boot. The potential benefit obtained from a closed injury is related to the reduction in contamination and likely infection.

Analysis of the cineradiography images demonstrated the inherent problem with a deflection strategy by showing that bony tissue damage occurs in the first few milliseconds from the initial shock wave, well before any gross movement of the limb from the blast wind. However, the amputation level for these

injuries is clinically determined by soft tissue disruption. This practice would suggest that deflection of the blast wind might have a major role in preventing the soft-tissue injury. Prevention of soft tissue damage with protective equipment could shift the clinical significance and medical outcomes from the soft tissue to the bone.

The MedEng boot was the only boot tested that integrated off-axis detonation into its design. While the boot resulted in better injury outcome predictions, a limited number of samples and the inherent potential difference in injury mechanism require further investigation.

Conclusion

Review of the blast injury literature demonstrates the lack of scientific understanding of blast physics in relation to wounding. New designs and engineering developments in protective footwear technology have succeeded in reducing injury severity. The potential ability to convert direct contact blast events into non-penetrating blunt trauma is the most promising direction for protective boot strategies. Once converted to non-penetrating blunt trauma, correlation to the automotive industry databases may be possible and allow for incorporation and evaluation of new protective measures. While current, commercially available landmine protective footwear does not prevent severe injury, severity reduction associated with certain types of footwear merits further investigation and refinement before adoption in the limited mine-clearance arsenal. ■

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