Fragmenting Munitions

3

John Breeze and Arul Ramasamy

3.1 Introduction

Energised fragments represent a heterogenous range of ballistic projectiles which are produced by an explosive event. Such encounters can occur in both the civilian environment due to terrorism as well as on the battlefield. In current conflicts fragmentation wounds have outnumbered those caused by bullets, with the UK and US experiences in Iraq and Afghanistan finding 74–81% of service personnel being caused by fragments [1, 2]. Bullet wounds tend to be more common in smaller scale conflicts such as the Falklands war or those involving jungle warfare or urban counter insurgency operations [3–5]. Excluding the effects of blast, the lethality of fragmentation weapons is generally far less than bullets, with the exception of artillery shells which produce large fragments at high exit velocities (in the region of 1500–2000 m/s) [6]. Hand grenades in particular are designed to produce a high number of small fragments and often incorporate spheres which are more aerodynamic and thereby increase effective range [7]. The result is to produce many multiply injured survivors that cause a greater burden on healthcare resources and the logistical chain. A large variety of munitions and devices are designed to produce fragments. Such munitions generally either utilise preformed fragments or the explosive force produced within the munition acts to break up the metallic casing (Table 3.1). Personal armour has altered the pattern of distribution of fragmentation injury so that the most common casualty seen on today's battlefield will have multiple extremity, neck, and facial wounds (Chap. 7) [8]. All war wounds are inherently

J. Breeze (✉)
Academic Department of Military Surgery and Trauma, Royal Centre for Defence Medicine, Birmingham Research Park, Birmingham B15 2SQ, UK
e-mail: johno.breeze@gmail.com

A. Ramasamy
The Royal British Legion Centre for Blast Injury Studies, Imperial College London, London, UK
e-mail: arul49@doctors.org.uk

J. Breeze et al. (eds.), *Ballistic Trauma*, https://doi.org/10.1007/978-3-319-61364-2_3

Table 3.1 A broad classification of explosive devices producing energised fragments

Type	Method of production	Material	Shape	Mass
Fragmentation grenade including rocket propelled	Preformed	Metallic	Generally spherical or regular	Low
Shell	Preformed	Metallic	Random	Large range from low to high
Mortar	Preformed	Metallic	Generally spherical or regular	Low
Antipersonnel mine	Preformed	Metallic	Generally spherical or regular	Low
Cluster munitions	Preformed	Metallic	Generally spherical or regular	Low
Improvised explosive device	Improvised	Metallic and non-metallic	Random, although often incorporate munitions above	Low

contaminated by organisms through soil, clothing, and skin, and this is potentiated in buried explosive devices such as mines. Bacteria include Clostridia, Streptococcus, Staphylococcus, Proteus, E. Coli, and Enterococcus, although infection is uncommon in small low-velocity wounds of the extremity. In addition, clinicians need to be aware of the presence of fungal infections (e.g. Aspergillus) following fragmentation injury. This is particularly common in incidents where the device has been buried in farmland. These infections result in significant morbidity, requiring multiple surgical debridements and often lead to sequential revision of amputation stumps [9].

3.2 Fragmentation Grenades

Fragmentation grenades can be hand thrown, underslung from a rifle or rocket propelled. The body may be made of hard plastic or steel. Fragments are most commonly produced by notched wire breaking up the plastic or steel outer casing or by depressions within the actual casing which create fragments by the expanding explosive force. The UK currently uses the L109A1 high explosive grenade as its primary device, with a lethal range of 20 m unprotected, and 5 m wearing body armour and helmet (Fig. 3.1) [10]. The M67 is the primary fragmentation hand grenade utilised by both US forces and Canadian forces and produces fragments that have a lethal radius of 5 m and can produce casualties up to 15 m, dispersing fragments as far away as 230 m. Such pre-formed fragments tend to be relatively light (often 0.1–0.4 g) but numerous [11], increasing the probability of a hit in lightly armoured soldiers but with reduced lethality. Under-barrel launchers increase the effective firing range of grenades to 150 m. The ubiquitous M203 single shot 40 mm grenade launcher is capable of firing a wide variety of grenade types including both high explosive and pre-fragmented rounds [10, 12]. The use of flechettes, depleted

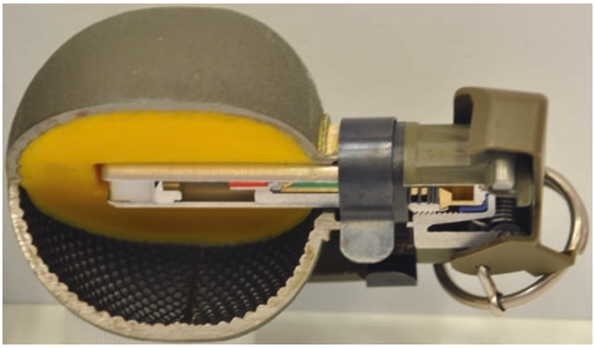

Fig. 3.1 Cross sections of L109A1 fragmentation grenade in which the core (*yellow*) contains an explosive which is ignited by the fuse and propels fragments each formed by dimples in the inner surface of the steel casing. Image courtesy of Dr. Debra Carr

uranium, and tungsten missiles capable of penetrating personal armour may further compound the complexity of wounding with toxicities that have yet to be defined, thus increasing the impact on the medical support system.

3.3 Antipersonnel Land Mines

Anti-personnel mines are a form of land mine and can be classified into blast mines or fragmentation mines. While blast mines are designed to cause severe injury to one person, fragmentation mines are designed to project small fragments across a wider area, and thereby causing a greater number of injuries [13]. Land mines have been deployed in 64 countries around the world and cause over 2000 victims a month with noncombatant far more likely to be injured than soldiers. Although banned by the Ottawa Convention of 1997 and prohibited by International Humanitarian Law, mines continue to be laid across the world. It is estimated that in countries with existing mine fields such as Cambodia, Angola, and Somalia, 1 in every 450 persons undergoes traumatic amputation [14]. Mines can be distributed by a plethora of weapon systems to include aerial delivery and Multiple Launch Rocket Systems (MLRS) that can deliver 8000 bomblets and 100 of mines m a matter of minutes. There are three broad classes of anti-personnel land mines based on mechanism of action (Table 3.2). Static mines are most commonly victim operated by the subject treading on them. Bounding mines can be either command detonated or victim detonated by means of trip wires [15].

The static mine is the most common type throughout the world. Upon contact and detonation, an instantaneous rise in pressure is produced, which along with the products and heated air produce a blast wave or dynamic overpressure. Contact with the body produces stress waves that propagate proximally along with shear waves produced by the blast effect [16]. Traumatic amputation occurs most commonly at the mid-foot or distal tibia [17]. Proximal to the variable level of amputation there is complete stripping of tissue from the bony structures and separation of fascial planes contaminated with soil debris, microorganisms, pieces of the device, footwear, and clothing (Fig. 3.2) [18]. Associated penetrating injury to contralateral limb and perineum are common.

Table 3.2 Broad classification of anti-personnel land mines based on mechanism of action

Type	Description
Static	Implanted in the ground and vary from 5 to 15 cm in diameter, contain 20–200 g of explosive
Bounding	Commonly known as the "Bouncing Betty", these devices have the highest mortality. A small explosive device is propelled 1–2 m above ground then explode, dispersing multiple small preformed fragments
Directional	Typified by the US M18A1 claymore which fires 700 steel spheres, each weighing 0.75 g in a 60° arc, with a range of velocities

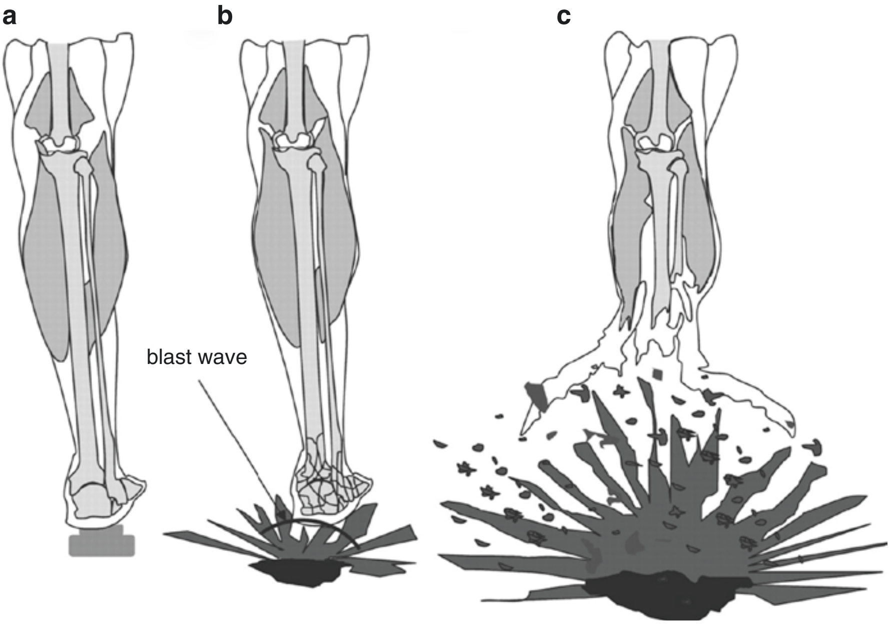

Fig. 3.2 Upon detonation of an anti-personnel mine (**a**), a blast wave is transmitted to the limb causing a brisance effect on the bones (**b**). Some 1–2 ms after detonation, the detonation products reach the limb and place huge stresses on the already damaged bone resulting in multiple fractures and potentially traumatic amputation of the affected limb (**c**). Reproduced with permission from [17]

3.4 Cluster Munitions

Cluster munitions are ordnance that deploy large amounts of explosives over a wide area and can be ground- or air-launched. They are multipurpose weapons with variants that target armoured vehicles, personnel and roads. They can also contain chemical weapons or lay landmines [19]. In general, they consist of a canister, which breaks open to release submunitions over an area known as a "footprint", which can be half up to a square kilometre (Table 3.3).

Table 3.3 Descriptions of a "cluster munition"- derived from [15]

A weapon designed to disperse or release explosive submunitions
Each munition contains greater than ten explosive submunitions
Each explosive submunition generally weighs less than 4 kg
Each explosive submunition is equipped with an electronic self-destruction mechanism or self-deactivating feature

It excludes those designed for air defence or which produce electronic effects

Cluster munitions represent a large proportion of Unexploded Ordnance (UXO) found on the battlefield due to their high failure rates (quoted between 5 and 30%) [20]. When used in areas of civilian and military cohabitation, they, almost guarantee civilian casualties. The military legacy of cluster munitions has been further questioned as a result of US troops being killed post-conflict by their own UXO, not to mention the impediment to mobility when operating in contaminated areas. Indiscriminate use and high failure rates are cited as the two areas of concern giving grounds for humanitarian scrutiny of cluster weapons, and according to research by the Cluster Munitions Coalition (a coalition working to ban cluster munitions internationally), at least 60% of casualties from unexploded cluster munitions are children [20]. There is a lack of accurate mortality and morbidity rates related to cluster munitions. The threat to civilians is certainly far less than from landmines, and it has been suggested that sub-munitions are unlikely to detonate unless handled or thrown. However those most likely to disturb and detonate devices are farmers or children, and there is a growing trend of collecting UXO for scrap metal. The International Committee of the Red Cross observed that those killed or injured by sub-munitions in Kosovo were five times more likely to be under 14 years of age than victims of anti-personnel mines. Such sub-munitions are often brightly coloured (making them attractive to children), lying on the ground and assumed to have failed to explode.

3.5 Artillery

The term artillery encompasses a huge range of weapons capable of producing energised fragmentation. The traditional types (guns, howitzers, and mortars) were sub defined by the trajectory followed by their projectiles. Guns and howitzers not mounted on tanks, ships, or aircraft are often called field artillery. Such pieces are generally dragged behind tractors or trucks or boarded on vehicles for their speedy execution. A gun is a weapon that has a low, or nearly flat, trajectory and fires projectiles in a nearly straight line. A gun's barrel is long in relation to its diameter. A Howitzer has a higher trajectory than a gun with less range than guns, but are capable of firing over the heads of friendly troops or to reach targets protected by hills.

A mortar is a weapon that fires explosive projectiles known as (mortar) bombs at low velocities, short ranges, and high-arcing ballistic trajectories. It is typically muzzle-loading with a short, often smoothbore barrel, enabling a greater rate of fire. The L16A2 81 mm light mortar is the system in current use by both the British and

Australian Army and supersedes the 60 mm mortar. It is a an indirect fire weapon with a maximum range of 5650 m and capable of firing up to 12 rounds per minute [21]. The previous 60 mm high explosive bomb were packed with TNT explosive producing approximately 590 fragments each with an average mass of 1.4 g. A rocket is a self-propelled projectile powered by a rocket motor, that differs from a missile in that it lacks an active guidance system. The UK currently uses the Guided Multiple Launch Rocket System (GMLRS), capable of accurately delivering a 90 kg high explosive warhead up to 70 km and can fire up to 12 rockets in less than 60 s [22].

3.6 Improvised Explosive Devices

An improvised explosive device (IED) is manufactured using easily available materials in order to have a destructive and disruptive effect [23]. IEDs are the most common cause of terrorist explosions in the civilian environment. That are also the most common threat to service personnel worldwide involved in counter-insurgency operations, and are the leading cause of injury and death for soldiers in modern conflicts [13]. IEDs can be manufactured using conventional weapons, or may be completely homemade. An IED consists of a casing, an explosive and a fusing mechanism with or without added material to create a fragmentation effect [24]. The casing of a homemade IED can be made out of diverse commonly available objects including metal cans, glass or polymer bottles and pipes [25]. Fragments impacting personnel may be of random or regular shape, originating from a preformed source (e.g. notched casing, ball bearings), added environmental debris (often referred to as shipyard confetti e.g. nails, ball bearings, screws, washers, bolts etc.) or the environment. In addition human body parts can be incorporated in wounds in suicide bombings (Chap. 5) (Fig. 3.3).

3.7 Retained Ordnance Within a Casualty

Although uncommon, retained live ordnance can occur in military military personnel wounded by explosively propelled devices, particularly from mortars and RPGs [26]. Such devices require a defined number of revolutions or a required distance and time before the missile is armed. There is therefore to potential for the device not to have exploded in such scenarios, particularly if the subject is hit very shortly after firing. A casualty with unexploded ordnance should be transported in the position found so as not to change the missile orientation and should always be grounded to the airframe if evacuated by air. These patients should be isolated and, in a mass casualty situation, should be treated last as the removal of ordnance is time consuming and the surgeon must attend to other casualties before placing his or herself at risk [15]. The basic guidelines for removal of ordnance are outlined in Table 3.4 [27].

Fig. 3.3 An IED cache including pressure plates and explosive material. Downloaded from Defence Imagery. Available from: http://www.defenceimagery.mod.uk/fotoweb/archives/5046-All%20News%20-%20Stock/Purged/ArchPurged/MOD/2012/April/Component%20Parts.jpg

Table 3.4 Removal of unexploded ordnance; adapted from Lein et al. [27]

Notify explosive ordnance disposal
No closed chest massage or defibrillation
Isolate patient from mass casualty situation and protect adjacent area (sandbagged bunker)
Protective equipment for medical personnel
Do not use cautery, power equipment, blood warmers
Avoid vibration, change in temperature, change in missile orientation
Plain radiographs should be undertaken to identify device
No computed tomography, or ultrasound to identify device
Anaesthetist (anaesthesiologist) to leave after induction
Surgeon and explosive ordnance disposal assistant only personnel present during removal
Remove device without changing orientation

References

1. Penn-Barwell JG, Roberts SAG, Midwinter MJ, Bishop JRB. Improved survival in UK combat casualties from Iraq and Afghanistan: 2003-2012. J Trauma Acute Care Surg. 2015;78(5):1014–20.
2. Owens BD, Kragh JF, Wenke JC, Macaitis J, Wade CE, Holcomb JB. Combat wounds in operation Iraqi freedom and operation enduring freedom. J Trauma. 2008;64(2):295–9.

3. Mellor SG, Cooper GJ. Analysis of 828 servicemen killed or injured by explosion in northern Ireland 1970–84: the hostile action casualty system. Br J Surg. 1989;76(10):1006–10.
4. Hardaway RM 3rd. Viet Nam wound analysis. J Trauma. 1978;18(9):635–43.
5. Jackson DS, Batty CG, Ryan JM, McGregor WS. The Falklands war: army field surgical experience. Ann R Coll Surg Engl. 1983;65(5):281–5.
6. Gurney RW. The initial velocities of fragments from bombs, shell and grenades, Report No. 405. Dayton: Ballistic Research Laboratories; 1943.
7. Breeze J, Leason J, Gibb I, Allanson-Bailey L, Hunt N, Hepper A, et al. Characterisation of explosive fragments injuring the neck. Br J Oral Maxillofac Surg. 2013;51(8):e263–6.
8. Breeze J, Breeze J, Allanson-Bailey LS, Allanson-Bailey L, Hepper A, Hepper AE, et al. Demonstrating the effectiveness of body armour: a pilot prospective computerised surface wound mapping trial performed at the role 3 hospital in Afghanistan. J R Army Med Corps. 2015;161(1):36–41.
9. Warkentien T, Rodriguez C, Lloyd B, Wells J, Weintrob A. Invasive mold infections following combat-related injuries. Clin Infect Dis. 2012;55(11):1441–9.
10. Rottman GL. The hand grenade. 1st ed. London: Bloomsbury Publishing; 2015.
11. Hill PF, Edwards DP, Bowyer GW. Small fragment wounds: biophysics, pathophysiology and principles of management. J R Army Med Corps. 2001;147(1):41–51.
12. Jones RD, Ness LS. Jane's infantry weapons 2011–201. London: Jane's Information Group; 2011.
13. Ramasamy A, Hill AM, Clasper JC. Improvised explosive devices: pathophysiology, injury profiles and current medical management. J R Army Med Corps. 2009;155(4):265–72.
14. Baskin TW, Holcomb JB. Bombs, mines, blast, fragmentation, and thermobaric mechanisms of injury. In: Ryan’s Ballistic Trauma. 2nd ed. Ballistic Trauma; 2005. p. 45–66.
15. Baskin TW, Holcomb JB. Bombs, mines, and fragmentation. In: Ryan's ballistic trauma. 3rd ed. London: Springer; 2011. p. 41–55.
16. Nechaev EA, Gritsanov AI, Minnullin IP. Mine blast trauma : experience from the war in Afghanistan. St. Petersburg: Russian R.R. Vreden Research Institute of Traumatology: Russian Ministry of Public Health and Medical Industry; 1995.
17. Ramasamy A, Hill AM, Hepper AE, Bull AMJ, Clasper JC. Blast mines: physics, injury mechanisms and vehicle protection. J R Army Med Corps. 2009;155(4):258–64.
18. Ramasamy A, Hill AM, Masouros S, Gibb I, Bull AMJ, Clasper JC. Blast-related fracture patterns: a forensic biomechanical approach. J R Soc Interface. 2011;8(58):689–98.
19. Dowlen H. Cluster munitions: should they be banned? J Conventional Weapons Destruction. 2015.
20. Dowlen H. Cluster munitions. In: Ryan's ballistic trauma. London: Springer; 2011. p. 57–66.
21. Ministry of Defence. 81mm mortar [Internet]. The British Army Website. The British Army; [cited 2017 Jan 4]. Available from: http://www.army.mod.uk/equipment/23224.aspx.
22. Ministry of Defence. GMLRS rocket launcher [Internet]. The British Army Website. The British Army; [cited 2017 Jan 3]. Available from: http://www.army.mod.uk/equipment/23276.aspx.
23. Oxley JC, Smith JL, Resende E. Determining explosivity part II: comparison of small-scale cartridge tests to actual pipe bombs. J Forensic Sci. 2001;46(5):1070–5.
24. National Academy of Engineering, National Research Council, Department of Homeland Security. IED attack. 2015. p. 1.
25. Thurman JT. Practical bomb scene investigation. 2nd ed. Boca Raton: CRC Press; 2016.
26. Thomson JD, Lisecki EJ. Injuries and deaths from collecting war souvenirs in operation desert storm. Mil Med. 1993;158(8):505–7.
27. Lein B, Holcomb J, Brill S, Hetz S, McCrorey T. Removal of unexploded ordnance from patients: a 50-year military experience and current recommendations. Mil Med. 1999;164(3):163–5.