Diplomarbeit

SURGICAL CARE FOR INJURIES CAUSED BY LANDMINES AND IMPROVISED EXPLOSIVE DEVICES

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Wien, 19.02.2017

Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Vienna, 19.02.2017 Sarah Arnim-Ellissen eh

I would like to thank the people who care for those caught up in someone else's war.

Abstract

BACKGROUND: Anti-personnel landmines and improvised explosive devices (IED) kill and injure more than 3,500 people each year. Recent developments in Afghanistan, Syria and Iraq led to an increased relevance of IED injuries in modern war surgery. The surgical care for those injured by landmines and IEDs is provided by civilian, humanitarian and military medical facilities.

METHODS: 65 publications by civilian and military medical facilities and a handbook for war surgery from a humanitarian organisation were reviewed in a meta-analysis. Key aspects of surgical care, agreed upon by civilian, humanitarian and military authors, were analysed.

RESULTS: The majority of landmine and IED victims sustain pattern I injuries leading to a high percentage of lower limb injuries and traumatic amputations. Traumatic amputations of the lower leg and injuries to the genitourinary or pelvi-perineal region are more frequent in recent years due to high amounts of explosives. Landmine and IED injuries consume more resources than other war wounds.

CONCLUSION: Key aspects of the successful surgical management for landmine and IED injuries are aggressive debridement, copious irrigation, early antibiotic treatment and early haemorrhagic control in civilian, humanitarian and military medical publications alike.

Zusammenfassung

EINLEITUNG: Antipersonenminen und Unkonventionelle Sprengvorrichtungen töten und verletzen jedes Jahr mehr als 3.500 Menschen. Jüngste Entwicklungen in Afghanistan, Syrien und dem Irak haben zu einer Zunahme des Einsatzes und daher zu einer zunehmenden Relevanz von Unkonventionellen Sprengvorrichtungen geführt. Opfer von Antipersonenminen und Unkonventionellen Sprengvorrichtungen werden entweder in zivilen Spitälern, Einrichtungen von humanitären Hilfsorganisationen oder des Militärs chirurgisch versorgt.

METHODEN: In einer Metaanalyse wurden 65 Publikationen aus zivilem oder militärischem Umfeld und ein Handbuch einer humanitären Hilfsorganisation qualitativ analysiert. Herausgearbeitet wurden dabei die in den Augen der zivilen, humanitären und militärischen Autoren wichtigsten Aspekte der chirurgischen Versorgung von Verletzungen durch Antipersonenminen und Unkonventionelle Sprengvorrichtungen.

ERGEBNISSE: Der Großteil der Opfer von Antipersonenminen und Unkonventionellen Sprengvorrichtungen erleidet Typ I Verletzungen und daher Verletzungen oder traumatische Amputationen der unteren Extremität. Traumatische Amputationen der unteren Extremität und Verletzungen des Genitales bzw. Perineum nehmen zu, da in den vergangenen Jahren in Unkonventionellen Sprengvorrichtungen eine größere Menge an Sprengstoff verwendet wird. Die chirurgische Versorgung von Verletzungen durch Antipersonenminen und Unkonventionelle Sprengvorrichtungen verbrauchen mehr Ressourcen als andere Kriegsverletzungen.

DISKUSSION: Laut Publikationen aus allen drei Kategorien gehören folgende Punkte zu den wichtigsten Aspekten der chirurgischen Versorgung: großzügiges Débridement, reichliches Spülen der Wunde, früher Start der antibiotischen Prophylaxe und frühe Blutungskontrolle.

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Acronyms

ATM	Antitank Mine
APBM	Anti-Personnel Blast Mine
APFM	Anti-Personnel Fragmentation Mine
APM	Anti-Personnel Landmine
CBO	Community Based Organisations
CCW	Convention on Certain Conventional Weapons
dB	Decibel
DCBI	Dismounted Complex Blast Injury
DPC	Delayed Primary Closure
GCS	Glasgow Coma Scale
GSW	Gunshot Wound
GU	Genitourinary
HO	Heterotopic Ossification
IAC	International Armed Conflict
ICBL	International Campaign to Ban Landmines
ICRC	International Committee of the Red Cross
IED	Improvised Explosive Device
i.m.	Intramuscular
i.v.	Intravenous
i.o.	Intraosseous
MESS	Mangled Extremity Severity Score
NIAC	Non-International Armed Conflict
NGO	Non-Governmental Organization
NSAG	Non-State Armed Group
NSAID	Nonsteroidal Anti-Inflammatory Drugs
PP-IED	Pressure Plate Improvised Explosive Device
PTVD	Post Traumatic Vessel Disease
RDX	Research Operated Formula X
RPBC	Red Packed Blood Cells
QID	quarter in die (four times a day)

SECS	Self-Expanding Covered Stent
TCCC	Tactical Combat Casualty Care
TIP	ter in die (three times a day)
TMP	Trauma Management Program
TNPD	Topical Negative Pressure Dressing
TNT	2,4,6-Trinitrotoluene
UN	United Nations
UNMAS	United Nations Mine Action Service
UXO	Unexploded Ordnance
VOIED	Victim operated Improvised Explosive Device
WW I	World War One
WW II	World War Two

Illustration and table directory

Rationale

Anti-personnel landmines and improvised explosive devices (IED) are a consistent threat to the lives and livelihoods of thousands of civilians who are caught up in the middle of someone else's war. Landmines and IEDs also led to unnecessary suffering for combatants, many times fighting someone else's war.

The mechanism of blast injury causes mutilation and often painful death.

The mechanism of deploying and activating landmines and IEDs indiscriminately affects the old and the young, men and women, civilians and combatants alike far beyond the years of armed conflict.

Understanding why and how landmines and IEDs keep on injuring and killing and understanding the surgical management of the arising injuries is an obligation to those people affected. Therefore, in this paper I aim to provide a comprehensive analysis for the contemporary surgical care of injuries caused by landmines and improvised explosive devices.

1 Introduction

1.1 Definitions

For the purpose of this scientific work the terms are defined as follows:

1. (Land-)Mine: Explosive or munitions placed underneath ground, on ground or close to the ground which is designed to be activated by the proximity of a person, vehicle or animal. The trigger mechanism can be a pressure plate or tripwire.
2. Anti-Personnel Landmine (APM): A mine (see above) designed to target a person, triggered by his or her proximity. The goal is to "kill or injure one or more people"(1).
3. Anti-tank mine/Anti-vehicle mine (ATM): A mine designed to target vehicles such as tanks or (armoured) cars, activated by the proximity, vibration or pressure of the vehicle.
4. Improvised Explosive device (IED): A collective term for non-conventionally produced (homemade) devices built to kill, injure or incapacitate a person or vehicle. In general, the term IED includes any homemade bombs like car bombs or suicide bombs. For the purpose of this thesis the term IED is used synonymous with victim-operated improvised explosive devices (VOIED), placed underneath ground, on ground or close to the ground activated by a pressure plate, tripwire or vibration, similar to a conventional landmine.
5. Minefield: An area in which mines have been placed in relative proximity to each other. The term includes marked and defined areas, as required by the UN Convention on Certain Conventional Weapons (2) (signs, fencing, recorded GPS-coordinates), as well as unmarked minefields.

1.2 Overview

Even though the total number of landmines and improvised explosive devices (IED) has been consistently dropping in the last two decades, they are still a threat to many civilians and combatants. In the past year over 3,500 people were killed or injured from landmines and IEDs (3). Most recently, developments in countries like Afghanistan, Iraq and Syria result in a new popularity of the use of improvised explosive devices, often made from materials that were obtained from old landmine-stockpiles (3,4).

Surgical care for victims of landmines or IEDs is either provided in civilian, humanitarian or military medical facilities. In times of armed conflict civilian and humanitarian facilities usually struggle with a lack of resources while military facilities are sometimes as well equipped as modern trauma centres.

The goal of this study is to analyse the surgical care for landmine and IED related injuries and to define universal key aspects for the surgical care agreed upon by civilian, humanitarian and military caregivers.

1.3 A History of landmines

1.3.1 Origins

The term landmine originates from the method of digging a mine underneath the opposing army or objects of strategic value. In 880 BCE engineers dug mines underneath city walls, stabilized these walls with wooden beams and eventually burned them so the mine would collapse and damage the city wall (5). After the introduction of black powder in Europe in 1241, which was invented in China about 400 years earlier, it was first used for guns and missiles (6). In 1403 the first recorded tunnel mine charged with black powder as an explosive was used in the war between Florence and Pisa. Leonardo Da Vinci was, as a military engineer, involved in its creation. Tunnel mines were used up until World War II (7).

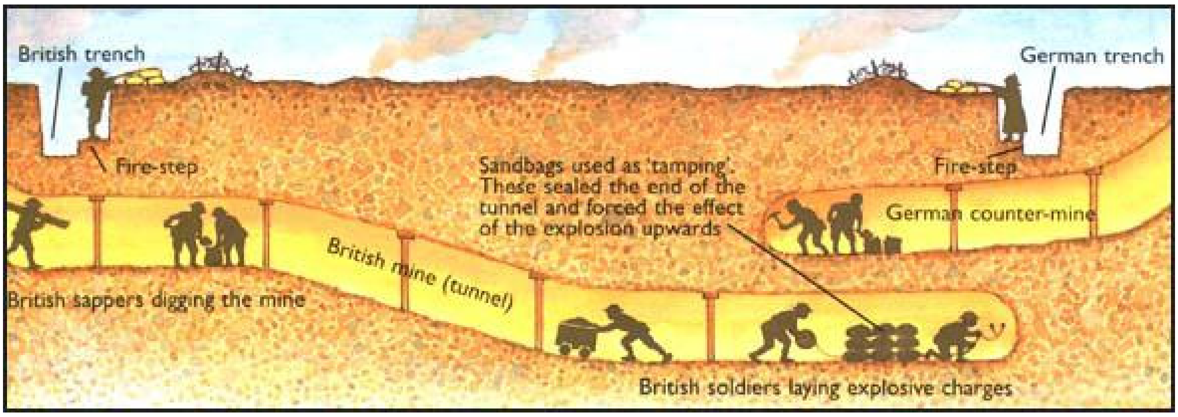

Figure 1 – Tunnel mine with explosives and counter-mine
Source: The greater war (5)

The first modern landmine, automatically activated by its target, was the so-called "fladdermine". A "ceramic container filled with around two pounds of gunpowder", developed by Samuel Zimmerman in Augsburg, Germany in 1573 (6,8). Black powder was later replaced with other kinds of explosives because of its high vulnerability to dampness (6).

In contrast to its original purpose, to break through enemy lines, in World War I landmines were used in defence against tanks (ATM). Whereas, modern anti-personnel mines (APM) as we know them today were developed to prevent de-mining of those antitank mines (9). The invention of 2,4,6-Trinitrotoluene (TNT) in the 1920s allowed the construction of reliable mines, as it replaced unreliable black powder (10).

1.3.2 Evolution of modern landmines and improvised explosive devices

The following years, especially during World War II, led to an increased variety in mines. Mines with poison gas such as the U.S. manufactured M23 (11) and even nuclear mines were developed (12). Blast Mines and different kinds of Fragmenting Mines will be discussed in chapter *1.5 on Technical Aspects*.

With the development of the first mobile metal detector in 1942, the so-called Polish mine detector, efforts were made to decrease the quantities of metal in the mines to make it harder to detect and demine. During World War II aluminium and steel were used. The first wooden mine PP MI-D went into production in 1939. In the 50s glass and plastic were used to create so called minimum metal mines with less than 3 grams of metal per mine (13).

Another development was the remote delivery of mines in the 1960s (10), which meant "a mine not directly emplaced but delivered by artillery, missile, rocket, mortar or similar means, or dropped from aircraft."(14). As such, scatterable mines are easier and quicker to deploy than those laid by hand. This leads to defensive and offensive strategic advantages. Mines delivered by artillery or aircraft can be used to cut off retreat or delivery routes, lead opposing armies into certain directions or simply hold them up and tie up resources for demining (15). A special form of remotely delivered mines was the JP 233, a British missile, which carried 30 submunitions, each containing 25.8 Kilos of explosives to destroy an airfield and 215 anti-personnel landmines to make a quick repair of the airfield impossible (16). Other commonly used remotely delivered mines were the US-American BLU-43 and BLU-44 used in the Vietnam War (1955-1975) as well as the Russian PFM-1 scattered in the Soviet-Afghan War (1979-1989). Through the method of deployment of scatterable mines the precise position of each mine can't be known and recorded (10). Therefore the use of remotely-delivered mines was and still is controversial within the international community because they are believed to be most likely to be used indiscriminately (17).

In 1983 the *UN "Convention on Prohibitions or Restrictions on the use of Certain Conventional Weapons which may be deemed to be excessively injurious or have* *indiscriminate Effects"* (CCW), also called the "*Convention on Certain Conventional Weapons"* and "*Inhumane Weapons Convention*"*,* entered into force (18). Signatory states included China, Russia and the USA, some of the biggest mine manufacturers. This treaty's goal was "to ban or restrict the use of specific types of weapons that are considered to cause unnecessary or unjustifiable suffering to combatants or affect civilians indiscriminately" (2). Included in this Convention is Protocol II, the "*Protocol on Prohibitions or Restrictions on the use of mines, booby-traps and other devices"*. Protocol II regulates technical details and applications for mines and other such devices allowed to use (19).

The Protocol II of the CCW forbids, among other things, the use of minimal metal mines and requires that

> "such mines shall incorporate in their construction a material or device that enables the mine to be detected by commonly-available technical mine detection equipment and provides a response signal equivalent to a signal from 8 grammes or more of iron in a single coherent mass." (14).

In consequence, this led to a decline in the production of minimal metal mines (6).

According to the CCW remotely delivered mines can still be used but the use is subject to certain restrictions. Before the deployment of scatterable mines an effective advanced warning has to be given to all civilians that might be affected. All mines have to be recorded on maps immediately and must comply with the provisions on self-destruction, self-deactivation and self-neutralization (14). For more detail see *chapter 1.3.3 on Legal regulations* and *chapter 1.5 on Technical aspects* of modern landmines.

After Protocol II of the CCW was amended in 1996 a large number of states and Non-governmental organisations (NGO) were pushing the idea of a total ban of anti-personnel landmines. Especially the International Campaign to Ban Landmines (ICBL) was lobbying for a total ban. A group of fifty states in favour of a global ban met in Ottawa, Canada in October 1996, to discuss the conditions and legal implementations. In the following year the Austrian Government drafted a first version that was discussed in the 51. UN General Assembly. At an expert meeting between states, the United Nations and NGOs in Vienna, Austria, the draft was adapted and later agreed on as a basis for negotiations at the International Conference for a Global Ban on Anti-Personnel Mines in June 1997 in Brussels, Belgium. After a three-week conference in Oslo, Norway, to discuss the treaty, the participants agreed on a final text that was introduced at the 52. UN General Assembly under the title "*Convention on the prohibition of the use, stockpiling, production and transfer of anti-personnel mines and on their destruction*" (20). The Convention was initially signed by 133 states in December 1997 and entered into force on 1 March 1999. In September 2016 the treaty, known as the "*Mine Ban Treaty*" or "*Ottawa Treaty*" (21), has been ratified by 162 states, including some of the most contaminated countries (22) like Afghanistan, Cambodia, Thailand, Iraq, Turkey, Yemen, Algeria, Chad, Angola and South Sudan (18). In 1997 the International Campaign to Ban Landmines (ICBL) was awarded the Nobel Peace Prize for its role in the development of this treaty (23).

Legal regulations and UN treaties on the use of landmines and other such devices led to changes in production and use. According to the annual Landmine Monitor, published by the ICBL, official trade of APMs ceased almost completely since the 1990s. All states that signed the Mine Ban Treaty, and many states that didn't, stopped the production of APMs, including major manufacturers like the USA. Modern conventional landmines are now produced by only eleven countries: **China**, Cuba, **India**, Iran, Myanmar, North Korea, **Pakistan**, **Russia**, Singapore, South Korea, Vietnam (CCW-signatory states are marked bold) (3). After signing the CCW China limited its APM production to self-destruction and self-deactivation mines (24). The Russian Federation claims not to export APMs that are not detectable or not equipped with self-destruction (25). But reports from actors like UN-peacekeepers, non-state armed groups (NSAG), civilians and medical NGOs show that signatory-parties regularly disobey the CCW and the Mine Ban Treaty. Russia, for example, is accused by Ukrainian officials to have provided APMs to the pro-Russian NSAGs in Ukraine including MON-50 mines, which are tripwire detonated even though tripwire is prohibited by the CCW (3).

Another major concern for the international community is the use of APMs and victim-operated Improvised Explosive Devices (VOIED) by non-state armed groups (NSAG). In 2015 it was estimated that NSAGs in seven countries produce VOIED or had access to improperly guarded state stockpiles of landmines (3). Although NSAGs are bound to International Humanitarian Law and treaties signed by the country they operate in, many do not comply with the rules laid out in the mentioned conventions (26). Booby traps, trip wires, mines without self-deactivating mechanisms and minimal metal mines are frequently used (3). Some NSAGs though are actively demining the area they control and provide victim assistance and mine education (27).

As long as modern warfare exists non-state armed groups (NSAGs) used homemade or improvised explosive devices of various types (6). Because of the shift towards asymmetrical conflicts involving multiple armed non-state parties, the use of IEDs becomes even more common (28) even though Protocol II of the CCW specifically prohibits the use of IEDs even for NSAGs (29). The total number of landmine victims has decreased since 1999; the number of casualties from victim-activated IEDs on the other hand has increased and is now responsible for about 30 % of recorded landmine victims (31 % in 2014). The majority of which has been recorded in Afghanistan, making up 76 % of all IED incidents recorded in 2014 (30).

1.3.3 Legal regulations

1.3.3.1 International Humanitarian Law

War always followed certain rules and codes of conduct, for example the time and manner of the beginning of a battle, but still was fought with great cruelty (31). In his book "Un souvenir de Solferino" (A memory of Solferino) Henry Dunant, who later founded the Red Cross, describes the horrors he saw at the battle in Solferino between the armies of Napoleon and the Austrian Empire. There he set up a makeshift field hospital at a nearby church in which all soldiers were treated, regardless from whose side. After seeing that much cruelty among the hostile troops he started wondering if there was a way to avoid unnecessary suffering, help the wounded and protect those delivering medical assistance (32). The publication of his book led to the creation of the Permanent International Committee of the Relief of the Wounded, today's International Committee of the Red Cross and, in consequence, to the first Geneva Convention of 1864 (33). The 16 states coming together at this convention agreed on the first internationally applicable convention to regulate the conduct of war, the "Convention for the Amelioration of the Conduct of the Wounded in Armies in the Field". The cornerstone of this agreement was the acceptance of the neutrality of medical personnel and medical facilities marked with a red cross on white background and the obligation to provide impartial medical assistance to all wounded in a conflict (34). This was the beginning of International Humanitarian Law (IHL). Many conferences and conventions followed in the years to come. The St. Petersburg Declaration (1868) brought regulations on explosive projectiles (35), the Brussels Declaration (1874) was a somewhat unsuccessful first attempt to implement general rules on the conduct of war (36), the Hague Convention (1899) regulated maritime warfare (37) and other Geneva Conventions, after World War I, dealt with questions regarding the treatment of the wounded and sick (1929) (38) and prisoners of war (1929) (39). During the First and the Second World War (WW I and WW II) the international community witnessed unprecedented cruelty against combatants and civilians. Chemical and nuclear weapons were used, prisoners of war were treated inhumanely and killed and the civil population was heavily affected by the fighting and specifically targeted. As a result of WW I and WW II the United Nations was founded in 1945 with its mission being peacekeeping and also being the patron of the international law (40). With the creation of the International Criminal Court, also in 1945, a judicial power for international law was established (41). Today IHL is complemented by several treaties regulating different aspects of warfare, like the Convention on Certain Conventional Weapons that regulates the use of "weapons deemed excessively harmful or indiscriminate in nature", including the use, stockpile and manufacturing of landmines (42).

The International Humanitarian Law (IHL) is also known as *jus in bello* or the law of war. In his book "International Humanitarian Law. A Comprehensive Introduction" Nils Melzer (2016) explains: "The purpose of IHL is to protect the victims of armed conflicts and regulate hostilities based on a balance between military necessity and humanity" (31). IHL distinguishes between international armed conflicts and non-international armed conflicts (43) but not all parts of IHL are applicable to both types (31). While most of the armed conflicts during the time of the creation of the IHL were international armed conflicts (conflicts between two or more state parties (44)) a group of scientists from the University of Uppsala in Sweden analysed todays conflicts and found out that the majority of these conflicts are non-international armed conflicts (conflicts between non-state armed groups or such non-state armed groups and one state party (44)) (45). Today the term "internationalized conflict" is often used but it is not a legal expression in IHL. It describes a non-international armed conflict with an international dimension, meaning that one, both or more sides are supported by a foreign state (46).

Non-international armed conflicts are regulated by common Article 3 and Additional Protocol II of the International Humanitarian Law (31), as well as some treaties including the Convention on Certain Conventional Weapons (CCW) (42). Therefore, the limitations in the use, stockpiling and manufacturing of landmines and similar devices are regulated under International Humanitarian Law, even in non-international armed conflicts. The CCW and Protocol II apply to all parties of a conflict no matter whether the party is a state in defence, aggressor state or non-state armed group. Even if IHL is broken by one party of the conflict other parties are not released from their obligation to comply with the law (14,42).

1.3.3.1.1 Convention on Certain Conventional Weapons and amended Protocol II

The use of landmines, booby-traps and other such devices is regulated in the UN-treaties *Convention on Certain Conventional Weapons* (entered into force 1983) - *Amended Protocol II on the Use of Mines, Booby-Traps and Other Devices* (amended 1996) (14,18) as well as the *Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction* (entered into force 1999) (18,21) for the signatory states.

The *Convention on Certain Conventional Weapons* (CCW) consists of four protocols (18). Protocol I prohibits the use of "any weapon the primary effect of which is to injure by fragments which in the human body escape detection by X-rays" (47). Protocol II regulates "prohibitions or restrictions on the use of mines, booby traps and other devices" (48). Protocol III deals with weapons that cause fire (19), Protocol IV with blinding laser weapons (49) and Protocol V with explosive remnants of war (50). The CCW as well as its Protocols were expanded to non-international armed conflicts in December 2001 (51).

Protocol II was part of the original Convention of 1981 and entered into force in 1983 (48), but was amended in 1996 to include new developments in landmines, improvised explosive devices and the deployment methods of those weapons (14). The *Protocol on prohibitions or restrictions on the use of mines, booby-traps and other devices as amended on 3 May 1996* (amended Protocol II) consists of 14 articles and a technical annex.

Article 1 emphasizes the application to non-state armed groups in a case of non-international conflict as "each party to the conflict shall be bound to apply" (14). Article 2 defines the terms used in the text. An anti-personnel mine (APM) is defined as "a mine primarily designed to be exploded by the presence proximity or contact of a person and that will incapacitate, injure or kill one or more persons." (14) The term "other devices" "[includes] improvised explosive devices designed to kill, injure or damage and which are actuated manually, by remote control or automatically after a lapse of time." (14) Article 3 deals with "general restrictions" on mines, booby-traps and other devices. It is prohibited to use devices that cause "superfluous injuries", devices that are designed to detonate in the presence of a mine detector and mines equipped with an anti-handling device (a device that causes the detonation of the mine when it is picked up) functioning after the mine has self-deactivated. It also points out that it is

> "prohibited in all circumstances to direct weapons […] either in offence, defence or by way of reprisals, against the civilian population as such or against individual civilians or civilian objects" (14)

and that

> "the indiscriminate use of weapons to which this Article applies is prohibited. Indiscriminate use is any placement of such weapons:(a) Which is not on, or directed against, a military objective. […]; (b) Which employs a method or means of delivery which cannot be directed at a specific military objective; or (c) Which may be expected to cause incidental loss of civilian life, injury to civilians, damage to civilian objects, or a combination thereof, which would be excessive in relation to the concrete and direct military advantage anticipated." (14)

Measures to protect civilian life have to be taken and each party is responsible "for all mines, booby-traps, and other devices employed by it" (14). Article 4 prohibits the use of mines, which are not detectable. Mines have to have a self-destruction and self-deactivation program or otherwise have to be marked, protected by fencing and monitored by military personnel as Article 5 and 6 explain. Article 7 prohibits the use of booby-traps and other devices in most circumstances because of its nature of surprise. Mines shall not be transferred from one High Contracting party to "States which are not bound by this Protocol" (Article 8). State parties must precisely record minefields, mined areas, mines, booby-traps and other devices employed by it. Therefore "the coordinates of at least two reference points and the estimated dimensions of the area containing these weapons in relation to those reference points" (14) has to be recorded. The records have to include "complete information on the type, number, emplacing method, type of fuse and life time, date and time of laying, anti-handling devices (if any) and other relevant information" of the mines, booby-traps and improvised explosive devices (Article 9 and Technical Annex). After an armed conflict has ceased the mines have to be "cleared, removed, destroyed or maintained" (Article 10). Article 11 points out that all parties have to provide technical knowhow, research and equipment needed to implement the Protocol. "Humanitarian and fact-finding missions of the United Nations Systems" as well as "[other] humanitarian missions" have to be especially protected from mines (Article 12). An annually conference will be held to discuss issues related with the protocol (Article 13). Via Article 14 all state parties are bound to "take all appropriate steps, including legislative and other measures, to prevent and suppress violations of this Protocol" (14). The Technical Annex deals with questions of recording, detectability, self-destruction and self-deactivation and marks and signs for minefields. All mines produced after the beginning of 1997 have to provide "a response signal equivalent to a signal from 8 grammes or more of iron in a single coherent mass" (14,42). Mines older than that shall "have attached prior to their emplacement, in a manner not easily removable, a material or device that enables the mine to be detected" also "equivalent of a signal from 8 grammes or more of iron". Scatterable mines have to be able to self-destruct or self-activate within 30 days. Less than 10 % are allowed to fail their self-destruction or self-deactivation but have to include a back-up self-deactivation feature that will deactivate the mine after 120 days (48).

The *Convention on Certain Conventional Weapons* was signed by 123 state parties, whereas the amended version of *Protocol II* was signed by 102 states, including Austria (1998), Croatia (1993), France (1998), Germany (1997), Iraq (2014), Israel (2000), Pakistan (1999), Russian Federation (2005), Turkey (2005), Colombia (2000), United Kingdom of Great Britain and Northern Ireland (1999) and United States of America (1999) (18). Non signatory states include heavily affected countries like Afghanistan, Algeria, Iran, Yemen, Thailand, Myanmar, Libya, Kosovo, Nepal, Cambodia and Somalia (48).

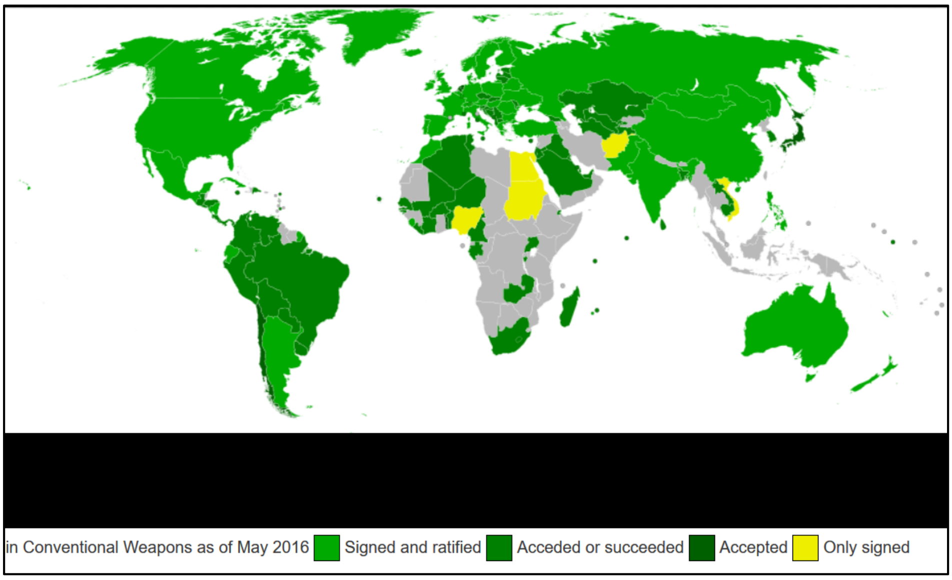

Figure 2 - Signatory status of the Convention on Certain Conventional Weapons Source: (131)

1.3.3.2 Ottowa Convention / Mine Ban Treaty

The *Convention on the prohibition of the use, stockpiling, production and transfer of anti-personnel mines and on their destruction* entered into force in 1996 for the signatory states (52). The convention was signed by over 80 % of the world's countries (53) and prohibits the use, development, production, stockpiling and transfer of anti-personnel landmines (APM). It also prohibits encouraging other states or parties to do so. The signatory states are furthermore obliged to destroy their existing stockpiles. Exceptions are made for APMs needed for training in mine clearance. Therefore, a small number of mines can be kept and transferred under certain regulations. APMs in mined areas, under the jurisdiction of signatory states, have to be identified, marked, protected by fencing and have to be destroyed "as soon as possible but not later than ten years after the entry into force of this Convention for that State Party". The convention emphasizes the exchange of information, know-how, human resources, and technical equipment for demining and the destruction of stockpiles between the states. Regular review conferences are convened by the Secretary-General of the United Nations to review the implementation of the treaty (21).

As of 2016, the treaty has been ratified by 162 states. Non-signatories are Armenia, Azerbaijan, Bahrain, China, Cuba, Egypt, Georgia, India, Iran, Israel, Kazakhstan, North Korea, South Korea, Kyrgyzstan, Lao PDR, Lebanon, Libya, Micronesia, Mongolia, Morocco, Myanmar, Nepal, Pakistan, Palestine, Russia, Saudi Arabia, Singapore, Sri Lanka, Syria, Tonga, United Arab Emirates, United States of America, Uzbekistan and Vietnam (52).

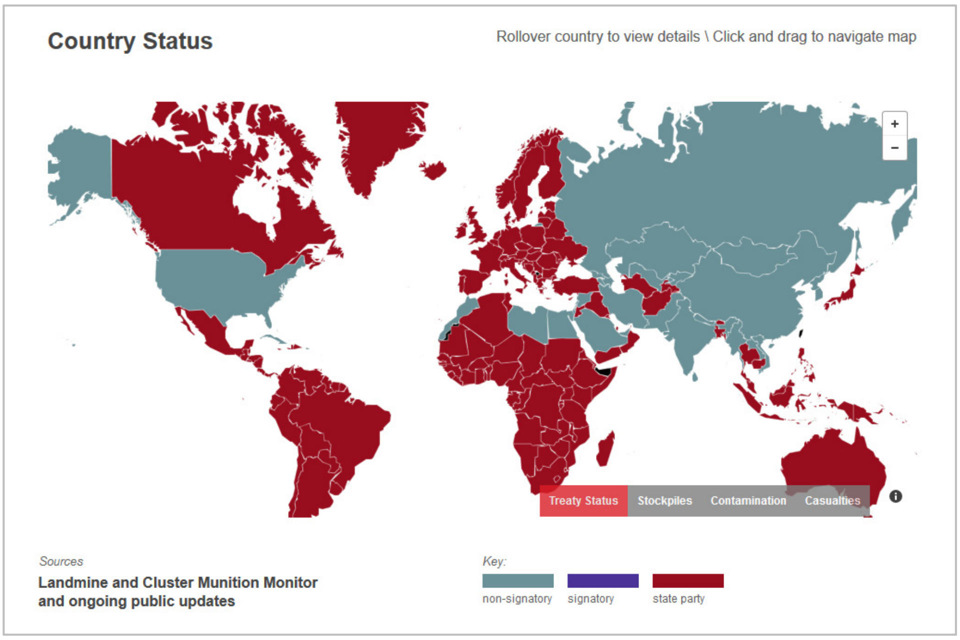

Figure 3 - Signatory status of the Mine Ban Treaty
Source: International Campaign to ban landmines – Webpage accessed 11.09.2016 (22)

1.4 The use of landmines and IEDs in contemporary warfare

Multiple factors play a role in the use of landmines and IEDs today. Legal regulations are believed to have implemented a de facto ban on the trade and therefore use of conventional landmines (3). Advanced technical possibilities, like self-deactivating mechanisms and regulations about fencing and recording were invented to protect civilians (48). But a shift towards complex armed conflicts with national as well as international aspects and state parties and non-state armed groups (NSAG) involved presents new challenges.

One could simplify and describe war as an armed conflict between two groups – two states or two tribes. In his book *Vom Kriege* from 1832 the military theorist Clausewitz described it like this: "Der Krieg ist nichts als ein erweiterter Zweikampf."[1] (54). Also, International Humanitarian Law (IHL) only distinguishes between international armed conflict (IAC) and non-international armed conflict (NIAC). International armed conflicts are armed conflicts between "two or more States". Non-international armed conflicts are armed conflicts "between governmental forces and non-governmental armed groups, or between such groups only" (55).

Todays armed conflicts are arguably more complex, with multiple states and non-state armed groups involved. In his paper on *New Wars* the lawyer Jed Odermatt (2016) argues that

> "[modern] wars are rarely categorised as being purely 'international' or purely 'non-international' in character, but are rather a mixture of internal and international conflict, taking place in a globalised context. Involving both states and non-state actors."

And carries on that today it is in fact "a mixture of all of these: profit making, criminal activity, foreign intervention and ethnic conflict", meaning that many different interests play part in todays armed conflicts (56).

The example of the war in Syria highlights today's complexity in warfare. A few of the involved groups are: the Syrian government, the Free Syrian Army (FSA, a NSAG), Islamic State in Syria and Iraq (ISIS, a NSAG), a US led coalition carrying out airstrikes and the Kurdish Peshmerga forces. The conflict is not confined to the Syrian territory but also reaching Iraq and Turkey. It can neither be categorised as a Non-International Conflict

[1] "War is nothing but a duel on an extensive scale." (138)

(US-, Turkish- and Russian-military forces are involved) nor as an international armed conflict (rebel groups against the Syrian regime) (57).

Many conflicts are similar to the one in Syria regarding its complexity, with multiple state forces and NSAGs involved. In many countries, most affected by anti-personnel landmines (APM) and IEDs, NSAGs are actively using APMs and IEDs. Between 2007 and 2008 various NSAGs used such devices in at least nine countries, according to a 2008 report by the International Campaign to Ban Landmines (ICBL) (58). In 2007 a total of 5.426 casualties by landmines, IEDs and Unexploded Ordinances (UXOs) were reported: 895 in Colombia, 811 in Afghanistan, 438 in Myanmar, 271 in Pakistan and 216 in Iraq (59). Among these NSAGs were the Revolutionary Armed Forces of Colombia (FARC), the Taliban in Afghanistan, the Karen National Liberation Army (KNLA) and others in Myanmar (58). Afghanistan persistently had the most landmine-victims each year since 2009 as shown in Figure 4 and Figure 5. The data also points to an increased use of IEDs by NSAGs.

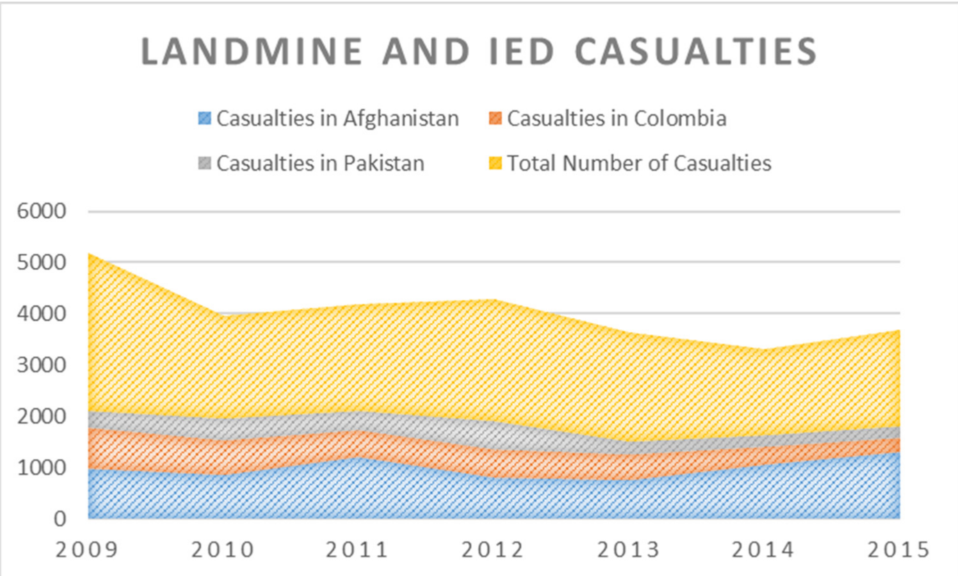

Figure 4 - Total number of casualties from landmines and IEDs 2009-2015 and sum of casualties in Afghanistan, Pakistan and Colombia
Source: Landmine Monitor 2009-2015 (3,60-65)

Figure 4 shows the decrease in the number of landmine victims worldwide between 2009 and 2015, but also the increase of victims in Afghanistan, which made up 35.24 % of all victims in 2015 (3,60–65). Afghanistan signed the Mine Ban Treaty in 2002 but is still waiting for its national parliament to implement it into legislation (18). The Afghani government reported the destruction of 525,504 stockpiled APMs between 2003 and 2007., plus additional 83,321 APMs since then. No use by the state military was reported but frequent use by NSAGs like the Taliban or the Haqqani Network of Hezb-e-Islami (66).

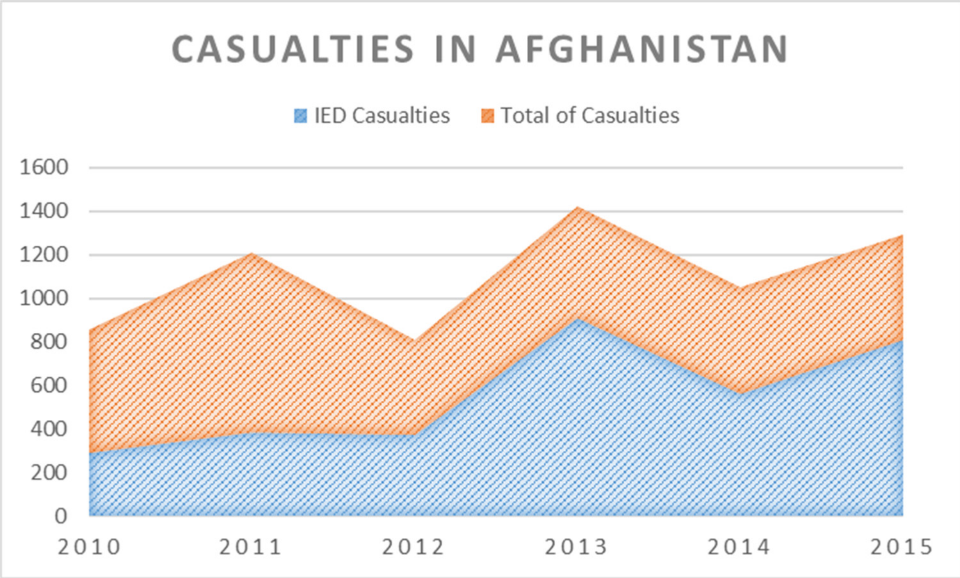

Figure 5 - Number of casualties from IEDs in comparison to the total number of casualties from landmines and other such devices in Afghanistan
Source: Afghanistan country profile for casualties and victim assistance (3, 60-65, 67-73)

Figure 5 shows the large proportion of IED incidents in Afghanistan in comparison with the total of all landmine and IED related incidents (3,60–65,67–73). Victim operated IEDs, especially pressure-plate IEDs (PP-IEDs) are now the most common form of blast injuries in Afghanistan, resulting in more than half of all victims from explosive devices in 2015 (66). PP-IEDs contain between 2 to 20 kg of explosives (74). The Taliban denied the use of victim operated IEDs in 2012 but reports of PP-IEDs around Taliban territory are frequent (66).

Other NSAGs are showing the will to stop the use of landmines and IEDs. In 2008 the Philippines Campaign to Ban Landmines developed the *Rebel Group Declaration of Adherence to International Humanitarian Law on Landmines*, which was later signed by four Philippine NSAGs. Also, the Democratic Party of Iranian Kurdistan and the United Jihad Council declared that they will no longer use landmines and IEDs in 2007 (58).

1.5 Technical aspects

Landmines can be divided into anti-personnel mines (APM) and antitank mines (ATM). Whilst APMs are activated "by the presence, proximity or contact or a person", ATMs are activated by tanks or other heavy vehicles (21). Improvised Explosive Devices can be victim-activated or activated by remote control (75). Besides explosives which are deliberately designed to be activated by the "presence, proximity or contact of a person or a vehicle" (21), unexploded ordnances of war (UXO) are a major threat. UXOs are weapons that have been launched without detonating on impact, but which might detonate when being manipulated on a later day. Grenades, mortar rounds, cluster munitions, submunitions, rockets, bombs or missiles can all become UXOs. Explosive remnants of war describe abandoned explosives including IEDs and UXOs, but not landmines (75).

For the purpose of this thesis the focus lies on APMs and victim-operated IEDs only.

1.5.1 Anti-personnel landmines

An anti-personnel landmine (APM) is designed to target a person, triggered by his or her proximity. The goal is to "kill or injure one or more people"(1). The Collaborative ORDnance data repository (CORD), a database for landmines and UXOs, lists 771 types of landmines, using at least 74 different kinds of explosives (76). 50 of these mines are regularly used or found. A distinction is made between anti-personnel blast mines (APBM) and anti-personnel fragmentation mines (APFM) (77).

All kinds of landmines and IEDs consist of at least the following components: the casing, a fuse, a detonator or booster charge and a main charge (77) with 8 to 500 grams of explosives (78). The fuse is activated by the victim causing the sensitive booster charge to react which then causes the main charge to explode. (77) The most common explosives used in landmines are TNT, Composition B, RDX and Amatolol (79).

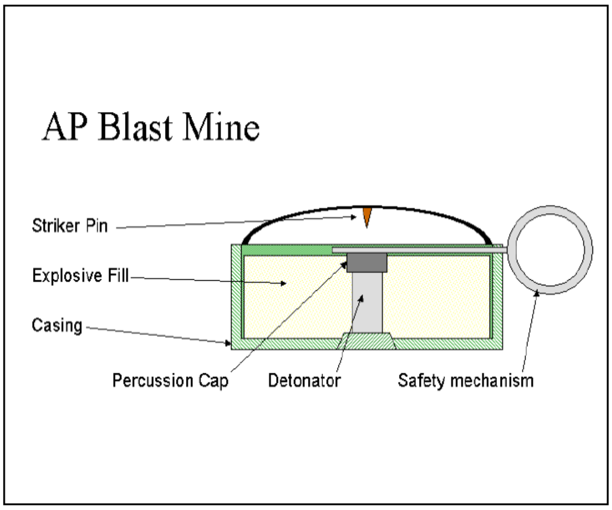

Figure 6 - schematic plan of an anti-personnel landmine
Source: Robert Keeley (80)

Anti-personnel blast mines (APBM) are usually small in size between 60 to 160 mm in diameter and 50 to 100 mm in height, of cylindrical shape and contain less than 100 grams of explosives. These small mines are usually buried close to the surface and activated by a person stepping on the mine. APBMs are designed to injure, rather than kill the victim, in order to block enemy-resources through the necessary complex first aid and evacuation. Butterfly mines are APBMs which are scattered by a plane, helicopter or artillery (75,80). Protocol II of the CCW restricts the use of scatterable mines. Advanced notice has to be given to the affected population and the mines have to be equipped with a self-destruction mode (48). Unfortunately, those restrictions were not always followed and butterfly mines, with their bright colour and extraordinary shape are particular dangerous for children who are attracted by those attributes (75). The explosive blast from APBMs usually leads to amputations of the lower extremity as well as injuries to the genitalia, abdomen and perineum (see *chapter 1.7 on Injury patterns*) (75,80).

Anti-personnel fragmentation mines (APFM) have a metal casing which is torn to pieces by the explosion or pieces of metal inside, which are propelled away from the mine when detonating, causing penetrating injuries. APFMs are commonly activated by tripwire and cause death or severe injuries to the people around. Stake mines are APFMs that are placed on a stake 200 mm above ground, usually camouflaged and activated by a tripwire. Once the stake mine explodes shrapnel is fired in all directions and usually causes death to people in at least a 4-metre radius. The construction of directional fragmentation mines causes the fragments to be projected “within a 60-degree horizontal arc and to a height of about 2 meters” in a 50-metre radius, according to the United Nations Mine Action Service (UNMAS) Handbook on landmines. They are or have been usually positioned facing away from defensive positions and towards the enemy. Bounding fragmentation mines are the third type of APFMs. Bounding mines are buried but a first explosion propels the mine one meter above ground where the main charge detonates, while the mine is in the air. The detonation fires fragments in all directions, similar to a stake mine. The bounding mine is also activated by tripwire (75,80).

1.5.2 Improvised explosive devices

Improvised Explosive Devices are a heterogeneous group of non-conventional weapons. They can be activated by a button, like in a suicide vest, with a remote control or victim operated (75). As mentioned before, this thesis will include only victim-operated devices. To be precise: victim-operated IEDs (VOIEDs) placed underneath ground, on ground or close to the ground activated by a pressure plate, tripwire or vibration, similar to conventional anti-personnel landmines. These kinds of VOIEDs can also be called dismounted IEDs (75,81,82).

An IED usually consists of a switch, an initiator, a main charge, a power source and a container (82). The initiator in VOIEDs is victim operated, with a pressure plate and tripwire as the most common forms. More sophisticated IEDs react only to certain vibrations or a certain tyre distance to identify military vehicles and spare civilian cars (83). The switch is responsible for the activation of the main charge, using electric or mechanic energy from the power source, often a simple battery or coil spring. The main charge can be a commercial/military explosive or an improvised/homemade explosive (82). Commercial or military explosives are often gathered from collected unexploded ordinances or landmines – this being one of the reasons for the importance of the destruction of stockpiles of old landmines. Homemade or improvised explosive devices are explosive mixtures made from available ingredients like the fertilizer Urea nitrate (82). There is a wide variety of containers used for IEDs, from minimal metal versions of wooden boxes or plastic bottles to booby traps like children toys or even human remains (82,83).

1.6 Explosion of a landmine

Most landmines and IEDs are activated by a pressure plate or trip wire. Both mechanisms close an electronic circuit which provides the energy to detonate the booster charge (82). The booster charge is a small amount of highly sensitive explosive material. This small booster explosion then leads to the explosion of the main charge (77). The amount and quality of the main charge determinates how devastating the explosion of the landmine or IED will be. The explosives demolition power is described through its R.E. factor, the relative effectiveness factor. It relates to the demolition power of TNT. TNT has an R.E. factor of 1, RDX an R.E. factor of 1.6, meaning that the explosive power of RDX is 1.6 times bigger than the one of TNT. Commonly used explosives in landmines have R.E. factors of 1.33 (Composition B), 1.60 (RDX) or 1.25 (Tetryl) (84).

The actual explosion consists of three elements: the positive-pressure shock wave, the negative-pressure suction wave and the blast wind. The detonation itself "is an exothermic chemical process that converts the explosive charge into high-pressure gases in an extremely short time" (78). Those high-pressure gases expand rapidly, displace an equal volume of air and soil and create the positive-pressure blast wave (85) which travels

Figure 7 - Illustration of the positive pressure blast effect in water (USS Iowa) Source: (85)

between 3,000 to 9,000 m/s, depending on the explosive used (78). The detonation velocity of the most common explosives in landmines are 6,900 m/s for TNT, 7,840 m/s for Composition B, 8750 m/s for RDX and 7,770 m/s for Tetryl (84). The blast wave consists of highly compressed air with a visible blast front at its leading edge (78) (illustrated by Figure 3) and causes the primary blast injury (86) through its shattering effect with pressures up to 300 bar (78,86). The positive-pressure shock wave builds up almost instantaneously but loses pressure rapidly "inversely proportional to the cube of the distance" (p/m^2) (78).

The second element is called negative-pressure suction wave. The displacement of the air leads to a relative vacuum causing surrounding air and small objects to be sucked in (78). A third component is the blast wind, a wind travelling behind the blast front. It is caused by the displacement of air by the explosion, travels much slower than the blast front but still reaches speeds between 100 to 670 m/s and a pressure of 6.9 bar (78,86). This highly energized wind reaches temperatures above 3,000°C (83).

1.7 Injury patterns

Each of the components of an explosion described above is associated with certain injuries to the victim. Primary, secondary, tertiary and quaternary blast injuries can be described. The circumstances of the blast injury highly determinate which of the components are most likely to inflict the most damage. Therefore, we will discuss the three types of mechanism in APM or IED related injuries first and then discuss the different kinds of blast injuries.

1.7.1 Mechanism of injuries caused by landmines and IEDs

1.7.1.1 ICRC classification

In 1991 ICRC surgeon Robin Coupland first distinguished three clinico-pathological patterns of landmine injuries which are widely accepted today (78,87). In a retrospective study with 757 patients he distinguished three patterns due to the injury-mechanism (88).

Figure 8 - ICRC classification for landmine injuries
Source: ICRC handbook on War Surgery, Volume 2, page 55 (88)

1.7.1.1.1 Pattern 1 injury

Pattern 1 describes the injury patterns for a person who stepped on a mine causing it to detonate. The most severe injury in these landmines or IED victims is the injury to the leg, usually causing a traumatic amputation of one foot, or parts of the leg which had contact with the mine or IED. The “contralateral leg, perineum and buttocks, abdomen, chest or arm” (78) are also frequently injured. The severity of the injury depends on the “amount of explosive material relative to the body mass of the victim and the position of the foot at the moment of contact” (78).

1.7.1.1.2 Pattern 2 injury

Pattern 2 injuries are caused by fragments from a landmine or IED exploding close to the victim, activated by a tripwire or someone else. Depending on the distance to the explosion and size and velocity of the fragments the injuries can range from superficial wounds to penetrating wounds or multiple traumatic amputations (78).

1.7.1.1.3 Pattern 3 injury

Pattern 3 injuries accrue when the landmine or IED explodes while a person is handling it. Those injuries are most common in children playing with mines, deminers trying to deactivate the mine or combatants laying the mine. The injuries most commonly seen are traumatic amputations of one or both hands and parts of the arms, injuries to the face, neck and eyes caused by the blast, the fireball or fragments. Burns to the airway increase the mortality rate of patients by a factor of three (78).

For the purpose of this thesis the primary focus will be on pattern 1 injuries

1.7.1.2 Bastion classification

The Bastion Classification was proposed in 2012 by a research team of the United Kingdom military. The goal was to implement a scoring system for lower limb injuries caused by IEDs, which describes injury patterns in detail and “correlates with management” (87).

The bastion classification consists of three parts. Traumatic amputations are described by the “most proximal extend of non-viable tissue or skeletal injury”. Segmental injuries are marked with the suffix “S” and follow the same classification from 1-5 as traumatic amputations. Additional injuries are identified by the suffixes A, B, C or D (87).

Class 1 includes injuries confined to the foot, class 2 are injuries to the distal or mid lower leg, class 3 are injuries to the proximal lower leg or distal or mid-thigh, class 4 includes injuries to the proximal thigh in which the application of a tourniquet is not possible and class 5 describes the most proximal injury to the buttock. “A” describes an injury to the intraperitoneal abdomen, “B” an injury to the genitalia or perineum, “C” a fracture of the pelvic ring and “D” describes injuries to the upper limbs (87).

An example: A victim sustained injuries to both legs. The left leg suffered a traumatic amputation of the mid lower leg. More proximal segmental injuries are seen on the same leg with its most proximal injury being to the mid-thigh. This injury is termed 3S. The right leg has no traumatic amputation but segmental injuries up until the distal thigh with viable tissue more distal. This injury is also classified as a 3S injury (87).

1.7.1.3 Gustilo classification

The Gustilo classification is used to classify open fractures. Injuries caused by landmines or IEDs are usually open fractures and can therefore be described using the Gustilo classification (89).

Type I describes an open fracture with a small wound (< 1 cm) caused by a low energy trauma. Type II fractures are caused by moderate energy and include a wound of 1-10 cm. Type III fractures are high-energy traumas and are divided in IIIA, IIIB and IIIC (89).

IIIA fractures are severe comminution or segmental fractures with extensive soft tissue defects and extensive contamination and periostal stripping. There are no neurovascular injuries. Local surgical coverage of the wound is still possible (89).

IIIB meets all criteria of an IIIA fracture but makes a free tissue flap or rotational flap coverage necessary since local coverage of the wound is not possible (89).

IIIC meets all criteria of IIIA but includes neurovascular damage, making vascular repair necessary. A free tissue- or rotational-flap is typically, but not necessarily, required (89).

Pattern 1 and pattern 3 injuries caused by landmines or IEDs are Gustilo Type III injuries per definition, due to the mechanism of a high-energy trauma to the limb (89).

1.7.2 Components to blast injuries

1.7.2.1 Primary blast Injury

The primary blast injury is a barotrauma caused by the positive-pressure shock wave (78). Primary blast injuries can be seen only in people standing close to the explosion (83), since the shock wave loses its kinetic energy quickly with distance (78). As soon as the body is hit by the shock wave a part of this overpressure is reflected and another part is absorbed. The kinetic energy, absorbed by the limb, causes a stress wave and shear waves in the tissue, damaging it depending on the tissues density (78,83,90).

The stress wave travels through tissue but is partially reflected on the divide between organs with different densities and therefore different acoustic impedance (91). The resulting pressure differentials are especially harmful between air- or fluid-filled organs and solid organs. The air or fluid is easily compressed from the positive-pressure shock wave but expands rapidly from the negative-pressure suction wave causing the organ to burst. This can lead to ruptured tympanic membranes, ruptures of the eye globe, implosion of air-containing cavities of the skull, injuries to the musculoskeletal system or intestine and the so-called blast lung (78). The stress wave also travels through and along the vessels, causing "fissuring of the tunicae intima and media, leading to thrombosis" and changes to the perivascular tissue, the so called post-traumatic vessel disease (PTVD) (78,92). Following gaps and softer tissue the stress wave travels far proximal along neurovascular bundles and bones, loosening those structures from its adhesions and providing a path for debris within the secondary blast injuries (78).

The share waves lead to the acceleration and deceleration of different tissues with different speeds, causing the tissue in between to overstretch and tear. Especially organs with a suspension, like the intestine, lung or placenta are vulnerable to those share waves (78,83).

1.7.2.1.1 Pulmonary Injuries

Pulmonary injuries, called blast-lung, are commonly seen at pressures of 4.8 bar, lethal in 50 % above 5.5 bar (90) and the deadliest injury of late blast mortality (78). The dense rib cage leads to multiple reflections of the pressure waves within the thorax causing severe lung damage with rupture of the alveoli and lung contusions (83). The rib cage itself might be damaged from the high positive pressure causing rip fractures that may lead to lacerations of the lung (83). The share waves can lead to a rupture of the suspension of the tracheobronchial tree. Pneumothorax, haemothorax, surgical emphysema (78) and in consequence adult respiratory distress syndrome are commonly seen 24 to 48 hours after the incident (78,83).

1.7.2.1.2 Injuries to the ear

The ear is the most commonly injured organ from primary blast. A pressure of 150 decibel (dB) is enough to injure the middle and inner ear (83). Especially when the auditory canal faces in the direction of the explosion, the shock wave travels into the canal and is reflected within the canal, increasing its damaging properties (78). “The rupture of the tympanic membrane is the most common injury” (78), but contrary to previous believes, does not necessarily indicate visceral trauma in the patient. Neither does the absence of a rupture of the tympanic membrane mean the absence of visceral trauma (83). However, according to the ICRC handbook on war surgery the clinical presentation of the patient usually involves “deafness, tinnitus, otalgia, [sic!] and ear discharge”. Injuries to the inner ear are common in those with tympanic injuries leading to dizziness. In most cases the patients recover after a short time and regain the full ability to hear (78).

1.7.2.1.3 Injuries to the musculoskeletal system

Since orthopaedic injuries are very common in APM or IED incidents, chapter *2.8.2.5 on Orthopaedic Trauma*, will describe those in detail.

1.7.2.2 Secondary blast Injury

Secondary Blast injuries are caused by debris or fragments of the mines casing which are energised by the explosion and act as projectiles (78). IEDs might have metal pieces or nails enclosed in the mine to serve as projectiles for the purpose of increasing the severity of injuries or number of casualties (83). In the case of more than one person being involved in the blast, pieces of clothing, bones and teeth from the person closest to the explosion can act as projectiles and injure the ones further away (83). The kinetic energy which displaces those debris or fragments can even displace blood cells within the vessel and cause the formation of a thrombosis in small vessels (78). The severity of the injuries caused by the fragments depends on the velocity, size and distance of the victim to the explosion. The fragments can cause wounds 20- to 25- times the size of the actual fragment due to their ballistic properties (83).

Debris energised from secondary blast mechanism travels along structures and is seen more proximal than the soft tissue and bone injury (78).

1.7.2.3 Tertiary Blast Injury

Tertiary blast injuries are caused by the blast wind that throws the victims of an explosion through the air on the ground or against an object, or by bigger objects being displaced and being thrown against the victim, like a car. The tertiary blast injuries are usually blunt trauma and can cause fractures, amputations, soft tissue lacerations, contusions and crush-syndrome (78,83,90,93).

1.7.2.4 Quaternary blast injury

Quaternary blast injuries are caused by thermal energy, by toxicity or events after the explosion that might lead to injuries or death. The most common injuries in this group are thermal injuries with burns from the fireball caused by the explosion which "may reach 3,000°C" (78). Pieces of metal which cause injuries or gases resulting from the explosion might act toxic (83). The explosion can also lead to the environment catching fire, the person being thrown into water or other endless scenarios that might lead to injuries or death (78,90).

1.7.2.5 Orthopaedic trauma

Since traumatic amputations are the most common severe injuries in victims injured by APMs or IEDs (93), orthopaedic trauma due to APMs and IEDs will be discussed in depth in this chapter. Orthopaedic trauma from blast injuries also follows the distinction into primary, secondary and tertiary injuries (94).

The signature injury mechanism in orthopaedic trauma from landmines and IEDs is the so-called umbrella effect. Hereby the kinetic energy and the accelerated fragments from the blast travel along the centre of the limb. This causes proximal injuries to the bone and other deep structures. Superficial soft tissue is driven outwards and away from the blasts energy and therefore less severely injured. The umbrella effect, as illustrated in Figure 9 by Ramasamy et al., causes a pyramid shaped loss of bone and soft tissue. (78,90,94).

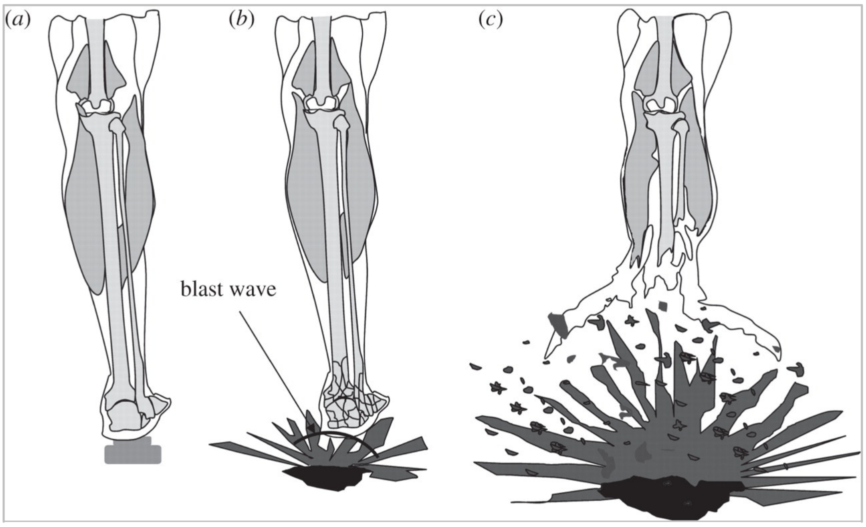

Figure 9 - Mechanism of the umbrella effect
Source: Ramasamy et al. (94)

1.7.2.5.1 Primary orthopaedic blast injury

As mentioned before, the primary blast effect originates in the effect of the blast wave. The blast wave enters tissue before displacement of the limb occurs. It causes „cellular disruption, soft tissue destruction and bone micro-fractures“ at the interfaces of tissues with differing acoustic impedance. Fractures caused by the blast wave are seen in victims close to the explosion (less than 50 cm away) (94).

An explosion beside the limb causes the blast wave to enter laterally and bend long bones. The blast wave leads to a peak stress in a specific area of the bone, depending on the height of impact of the blast wave and the anatomy of the bone. For the tibia, this peak stress accumulates in the upper third (94), causing below knee fractures and traumatic amputations to be most likely at the height of the upper third of the tibia (78,93–95).

In the case of pressure plate activated APMs or IEDs the blast wave enters the limb within 200 µs. The blast wave then travels along weak soft tissue, like "areolar tissue around neurovascular bundles and fascia planes"(78). The blast wave has a shattering effect on the bone, called the brisance effect. This leads to compound fractures with multiple fragments (94). The soft tissue connected to the bone, muscles and periosteum, is stripped off and "pushed up and out". This causes more severe damage to deep structures, superficial muscles are less damaged (78). This is the first phase of the so called umbrella effect as described above (78,94).

This mechanism makes the bone vulnerable for additional forces. As a result of secondary and tertiary orthopaedic blast injury to the exposed bone, traumatic amputations are likely (93,94). The blast wind is another dynamic force which might lead to "avulsion through the fracture site" (93).

1.7.2.5.2 Secondary orthopaedic blast injury

Fragments from the APM or IED or other accelerated material cause the secondary orthopaedic blast injury (94). The shattering effect of the fragment depends on its velocity, size and the path it travels through the tissue. Direct trauma from fragments with a minimum of 1.05 grams travelling at 185 m/s causes complete fractures. The fragment enters the first cortex, into the medullary cavity damaging the trabeculae and creating a cavitation – similar to a bullet. If the fragment travels fast enough it exits through the second cortex with an enlarged exit wound (94) due to the tumbling movement of the fragment which increases the tissue damage (93). The bone fragments usually have no periosteal connection, therefore no blood supply and have to be operated (94).

If the fragment travels to slow a so-called ‘drillhole’ fracture with only one cortex damaged, is sustained. These fractures can usually be treated conservatively (94).

An indirect fracture can occur if the fragment travels through soft tissue right next to the bone, causing injuries “by the high pressures exerted on the bone surface by the leading edge of the rapidly expanding temporary cavity.” Fractures of this nature can also usually be treated conservatively (94).

This second phase of the umbrella effect, of a limb injured by an APM or IED, is due to the mechanism of secondary orthopaedic blast injury. The bone was first shattered from the blast wave as a primary orthopaedic blast injury. After that, fragments contact the limb in 1 to 2 ms. This causes even more fragmented fractures of the already injured bones and injuries to the soft tissue. The fragments concentrate in the centre of the limb causing a pyramid shape of the amputated limb and leaving viable and/or non-viable tissue distal to the most proximal bone amputation (94).

In Vol. 2 of their handbook on War Surgery the ICRC describes blast mine injury as “the ‘perfect’ example of the dirty and contaminated war wound.” The blast tears through the tissues, driving oil, grass, gavel, metal or plastic fragments of the mine casing and pieces of shoe and bone fragments of shattered foot, up into the leg.” (78)

1.7.2.5.3 Tertiary orthopaedic blast injury

The tertiary blast injury occurs when the victim is displaced and thrown against the ground or an object, or if an object is displaced and thrown against the victim. Ramasamy showed in his study (2011) on blast-related fracture patterns that “loads applied perpendicular to the axis of the bone” lead to “wedge fractures [that] originate at a location directly opposite the point of impact” (94). In pressure plate activated APM or IED related injuries the load effects the bone along its axis. This leads to “comminuted calcaneal (heel) [sic!] fractures” (94).

1.7.2.5.4 Dismounted Complex Blast Injury

Due to an increase of explosive material in IEDs more proximal injuries occur more often since 2009 or 2010 (4,96–98). Therefore, the term *Dismounted Complex Blast Injury* (DCBI) was created. It describes:

> "injuries to the bilateral lower extremities (usually proximal transfemoral amputations) and/or upper extremity (usually involving the non-dominant side), in addition to open pelvic injuries, genitourinary, and abdominal trauma." (99)

The injuries summarised as dismounted complex blast injuries lead to specific challenges in surgical care and resuscitation.

2 Methods

The surgical care for the victims of landmines and improvised explosive devices (IEDs) was analysed via a meta-analysis of available literature on the topic.

A special focus was laid on the differences between preclinical, surgical and resuscitative routines in civilian, humanitarian and military settings.

2.1 Literature research

Before the United States' military intervention in Afghanistan the global number of landmine victims decreased every year. Starting immediately after the terrorist attacks from 11 September 2001, this military intervention led to a massive increase of the use of improvised explosive devices by non-state armed groups against the coalition forces. It also led to the set-up of multiple military hospitals, capable of surgical intervention and consequently to more research in this area (3,59–62,64,65,67–71,100–102). Therefore, 11 September 2001 was used as starting date for this meta-analysis, with 13 August 2016 as its end-date.

All literature on the surgical care of injuries caused by landmines or improvised explosive devices available in Full Text version on the PubMed, the online US National Library of Medicine from the National Institutes of Health, was included.

2.1.1 Search terms and results

The following search term was used to find publications on landmines:

landmine[All Fields] AND ("loattrfull text"[sb] AND ("2001/09/11"[PDAT] : "2016/08/13"[PDAT]))

The search result consisted of 101 publications. The publications were either from civilian or military authors.

The following search term was used to find publications on improvised explosive devices:

(improvised[All Fields] AND explosive[All Fields] AND ("equipment and supplies"[MeSH Terms] OR ("equipment"[All Fields] AND "supplies"[All Fields]) OR "equipment and supplies"[All Fields] OR "device"[All Fields])) AND ("loattrfull text"[sb] AND ("2001/09/11"[PDAT] : "2016/08/13"[PDAT]))

The search result consisted of 128 publications. The publications were either from civilian or military authors.

It is remarkable that PubMed provides 134 items for the search term "improvised explosive device" (full text) with no restrictions in the publication date. But 128 items if the dates are restricted to 11 September 2001 until 13 August 2016. This means that before 11 September 2001 hardly any notice was given to improvised explosive devices in medical literature and suggests an increased significance of this topic (103).

2.1.2 Relevance

Of the 229 results, for the search terms "landmine" and "improvised explosive device" in the 15-year-period, 65 were considered to be relevant to this topic. Included were all publications on the epidemiology of surgical care, operative resuscitation, surgical methods, surgical case reports, preclinical aid, perioperative care and community based medical care. Excluded were publications on epidemiology, mechanism of injury (even though those were used in other parts of this thesis) and other publications with a topic unrelated to this thesis. Therefore, contents of 65 relevant publications were included in the following analysis.

2.2 Handbook on war surgery

In addition to the literature research on PubMed the handbook *"War Surgery. Working with limited resources in armed conflict and other situations of violence"* was used to analyse contemporary guidelines on war surgery from a humanitarian organisation's point of view.

The International Committee of the Red Cross (ICRC) recently published this handbook in two volumes. The surgical care for victims of landmines or IEDs is one of several focuses in volume 2. The handbook serves as a guideline for ICRC-surgeons on the surgical treatment for injuries caused by landmines and IEDs (78,104).

2.3 Goal

The goal of this meta-analysis was to determine key factors of the surgical care for landmine and IED victims on which civilian, humanitarian and military care givers can agree on and to map out differences in those settings.

3 Results

3.1 Epidemiology and injury patterns

Most of the analysed research on landmine and dismounted IED injuries find that injuries or traumatic amputations of the lower extremity are the most common injuries encountered in landmine and IED victims, suggesting pattern 1 injuries to be the most common mechanism of injury. The incidence of lower limb injuries or amputations varies depending on the patient cohort but almost all publications show a high proportion with 63.5 % (105), 63.5 % (106), 52.6 % (107) and 81.3 % (108) – mean 62.2 % – of all injured patients and 48 % (81) of those patients dying from the landmine and IED injuries. Injuries to the head, face and neck occur in a mean of 27.3 %, upper limb injuries or amputations in a mean of 36.3 % and torso injuries in a mean of 18.3 % of all (105–108) landmine and IED victims and 23 %, 3 % and 21 % (81) of those dying from their blast injuries.

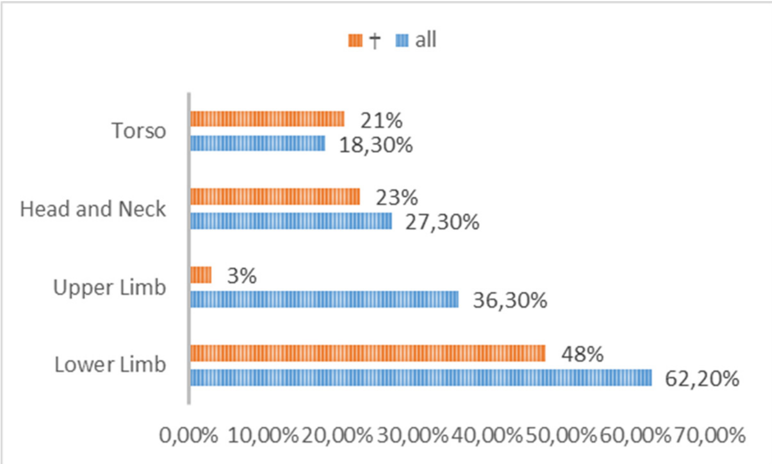

Figure 10 - Distribution of injuries (blue: all; orange: dying from the blast)
Source: (81, 105-108)

	Afshar	Jackson	Shabila	Soroush	Singleton †
Head		14.2 %	12.3 %	21.9 %	19.0 %
Face	24.3 %	32.0 %			1.0 %
Neck		4.6 %		0.7 %	3.0 %
Thorax		17.3 %	5.3 %	4.1 %	8.0 %
Abdomen	9.3 %	27.4 %	3.5 %	6.2 %	13.0 %
Spine		17.8 %	2.5 %		3.0 %
Upper Limb	32.6 %	55.8 %	16.8 %	39.9 %	3.0 %
Lower Limb	52.6 %	63.5 %	63.5 %	52.6 %	48.0 %

Table 1 - Distribution of landmine and IED injuries in all patients (Afshar, Jackson, Shabila and Soroush) and those dying † from the blast (Singleton)
Source: (81, 105-108))

The actual mortality from landmines and IEDs can only be estimated, because it is assumed that a big percentage of landmine/IED victims die on site or before reaching the hospital. In their patients, the ICRC estimates a field mortality rate of 13.4 % in Afghanistan between 2001 and 2006, while their in-hospital mortality rate is 3.7 % (78).

Afshar et al. (2007) and Beckett et al. (2012) report similar in-hospital mortality rates with 2.1 %, 3.8 % and 4.45 % (73,106,107). Walsh's paper (2003) on the rehabilitation of landmine victims points out that it can be estimated that 50 % of the landmine victims die within the first hours after the incident and will not reach a hospital in time. Therefore, they will not be recorded. According to the paper only 25 % of landmine victims are able to reach a hospital within six hours. It has to be pointed out that the paper refers to older sources, from around 1995. (109) Shabila et al. describe 285 patients injured by landmines in Afghanistan. The in-hospital mortality rate was 2.1 %, all of which died within the first 24 hours. Again, it was suspected that many victims died before arriving at the hospital (106).

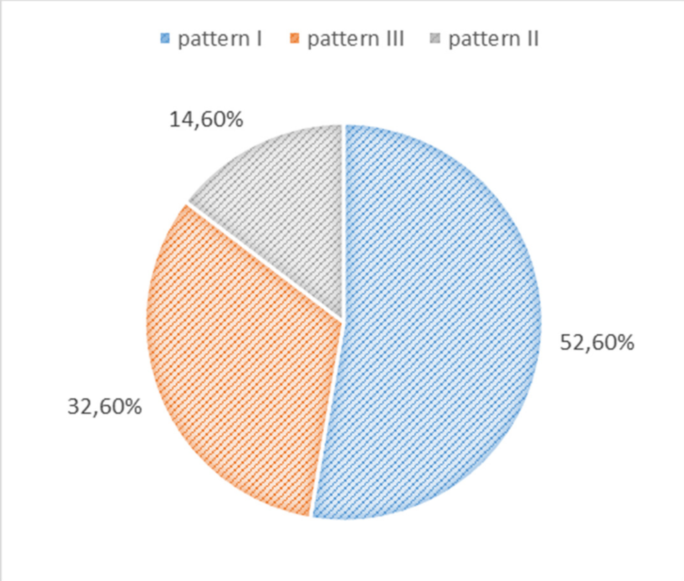

Figure 11 - Distribution of wound patterns at Motahhary Hospital, Iran
Source: Afshar et al. (107)

Mossadegh et al. report a high mortality rate in patients with pelvi-perineal or genitourinary trauma. Out of 118 patients with pelvi-perineal injuries only 62 (53 %) survived. The highest mortality rate was seen in patients with a combination of perineal injuries and pelvic fractures (73 %). Patients with a grade III anteroposterior-compression fracture of the pelvis in combination with perineal injuries died in 93 % of cases. The survival rate was closely linked to the injury pattern, massive transfusion and the use of antibiotics. Patients with combined perineal injury and pelvic fracture needed up to 38 units of packed red blood cells (PRBC) and fresh frozen plasma (FFP). In a setting with limited resources, mortality rate and the necessity for massive transfusion can act as parameters for triage (97).

The most common cause of death for IED victims is exsanguination from lower extremity amputations (42.6 %), followed by haemorrhage from the low abdominal aorta or iliac arteries (22.2 %) and traumatic brain injury (18.7 %) as Singelton et al. (2013) showed in their 2013 publication on "unexpected survivors" of IED blasts (81).

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Research on cervical spine injury from dismounted IEDs analysed patients at Kandahar Airfield Hospital in Afghanistan between 2008-2011. 326 out of 15,693 patients admitted were injured due to dismounted IEDs. 96 suffered amputations: 4 had isolated upper limb amputations, 8 isolated lower limb amputations. But the majority of 84 suffered combined amputations of the upper and lower limb (110). This illustrates the destructive power of IEDs, which often use high amounts of explosives (74,110).

Furthermore, the study describes victims injured by dismounted IEDs at low risk for cervical injury. Out of 326 people injured by dismounted IEDs only 19 sustained injuries to the c-spine, 4 of which were radiographically unstable. All 19 patients had traumatic amputations to the lower limbs. Despite most first response protocols recommending c-spine immobilisation, only 7.6 % of the total number of patients had c-spine immobilization. None of the patients receiving c-spine immobilization actually sustained c-spine injuries. The study questions the necessity of c-spine immobilisation in all patients injured by dismounted IEDs, but suggests that those with amputations to the lower extremity might profit from c-spine immobilisation (110).

In their study on injuries due to landmines in Shahid Motahhary Hospital, Iran, Afshar et al. (2007) analysed 156 victims of landmines. 52.6 % of the patients suffered pattern 1, 32.6 % pattern 3 and 14,6 % pattern 2 injuries (107).

Among the 156 patients 6 died, the other 150 had a mean of 1.9 surgeries (286 surgeries in total) and a hospital stay of 16.8 days. A total of 110 surgical amputations were carried out. Due to the majority of the patients suffering pattern 1 injuries, surgical amputations of the lower limb were more common (71 amputations or 64.5 %) than upper limb amputations (39 amputations or 35.5 %). Other common injuries were injuries to the torso or neck from shrapnel (14 victims) and eye injuries (35 victims). Eye injuries were most common in patients suffering pattern 3 injuries (25 victims). 140 victims reached a medical facility within the first 6 hours after the incident (107).

Another study from Iran by Shouroush et al. (2008) analysed 3,713 patients injured by landmines. 1,499 of those patients underwent surgical amputations with the most common being a below knee amputation (108).

Multiple publications (73,97,105) show an intensive need for resources for the surgical and resuscitative care for patients with the mechanism of injury being an explosive blast from a landmine or IED due to the high Injury Severity Score, the complexity and the extensive blood loss. Jackson et al. (2014) analysed 388 UK military casualties. About half (50.5 %) of those injured, were victims of improvised explosive devices. These 196 IED victims were consuming the highest amount of resources. While median hospital stay was 10.6 days for all 388 patients, the hospital stay of IED victims lasted for 17 days on average. Mid ISS of all patients was 5.0 and NISS 7.5, while IED injuries had an ISS of 9.0 and NISS of 12.0. Injuries caused by rocket propelled grenades lead to similar hours in the operating theatre with 150 minutes per person on average, while IED-injuries led to 145 minutes per person, on average (105).

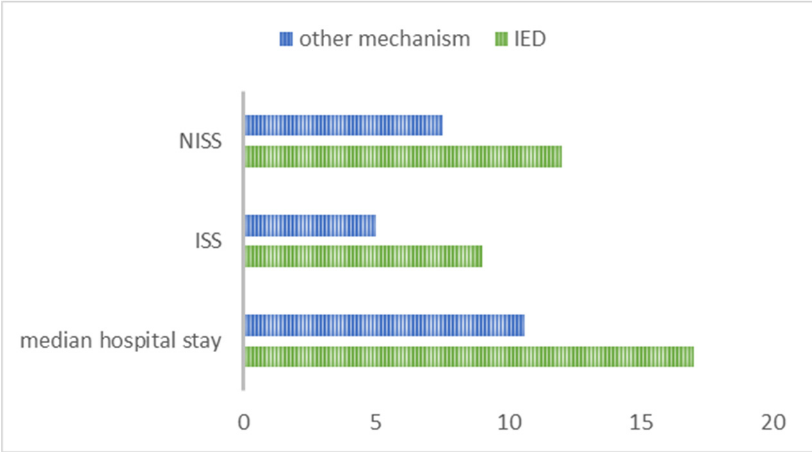

Figure 12 - Comparing injury severity and resources needed
Source: Jackson et al. (105)

Another interesting finding in the Jackson et al. paper was that the distribution of lower and upper limb injury was unusual in the 196 patients with IED injuries. While most studies show significantly more injuries to the lower extremity (106–108), i.e. pattern 1 injuries, this study shows almost equal distribution: 110 IED victims sustained injuries to the upper extremity and 125 to the lower extremity. It can be assumed that these military IED-victims regularly suffered pattern 3 injuries due to handling the IED, which also correlates with the relatively high number of injuries to the face (63 patients) and head (28 patients) (105).

Tahir Khan et al. describe the surgical care for 28 patients who suffered hindfoot injuries due to landmines. 24 of the patients, or 78 %, suffered injuries that made surgical below-knee amputations necessary. The study group described the amputations necessary as “usually a completion of the traumatic amputation”. 19 patients underwent distal tibial amputation, 3 a forefoot amputation and the other 2 a more proximal below-knee amputation. Out of the 24 patients only 2 reached the hospital within 24 hours. The 22 patients who reached the hospital later than 24 hours after the injury presented with muscle necrosis and deep wound infection with mainly anaerobic bacteria. The procedure always included radical debridement of soft tissue and bone fragments, the amputation at the appropriate level allowing coverage with viable soft tissue and a free tissue transfer (111).

Recent literature on IED and landmine related injuries report an increase in the number of IED casualties as well as more severe injuries (for details on the increase in IED casualties see chapter 1.4 The use of landmines and IEDs in contemporary warfare) This is likely due to bigger amounts of explosive material in contemporary IEDs. High traumatic amputations, in many cases bilateral, of the thigh in combination with pelvi-perineal, genitourinary (GU), anal and abdominal injuries are becoming more common (4,97,98). Moussadegh et al. (2012) analysed the UK Joint Trauma Registry for pelvi-perineal trauma (97) and Banti et al. (2015) analysed the US Department of Defence Trauma Registry for genitourinary trauma (4) in a similar time period (2003-2010 and 2001-2011). Both studies describe an increase in those injuries in the later study period (4,97). Banti et al. even speak of an increase in genitourinary injury of nearly fivefold between 2010 to 2011 (4). Williams et al. agree with those findings, reporting that 10.6 % of all injured UK military personnel in Iraq and Afghanistan sustained genitourinary injuries with scrotal injuries being the most common (15 %) (112). According to Banti et al. scrotal injuries (39 %) and testicular injuries (36 %) are the injuries most likely encountered in those suffering genitourinary injuries. Penile injuries with 20 % and urethral injuries with 5 % were less frequently seen in patients with genitourinary injuries recorded in this study. Most injuries were caused by the secondary blast, with accelerated IED-fragments causing penetrating injuries. The most severely injured organs reported were the testicles with 77.6 % of those injuries involving tissue loss and 37 % resulting in a Grade V injury with testicular destruction (4).

3.2 Preclinical management and transportation

Between civilian, humanitarian and military settings preclinical management can differ a lot. In the military setting strict chains of medical care and evacuation are followed. How civilian and humanitarian organisations handle first aid and transportation of the wounded can hardly be summarised, because of stark differences in the availability of resources, varying external circumstances on the ground and divergent strategies. The following chapter will try to summarise those different realities as depicted in the reviewed literature. A chapter on community based medical aid for victims of landmines or IEDs can be found further below in chapter 3.7 on Community-based medical care.

3.2.1 Availability and application of first aid

Soroush et al. (2008) looked at the pre-clinical care for 3,713 landmine victims in a civilian setting in Iran. Over all 10.6 % of all patients in this study received pre-clinical care. 8.3 % received haemostasis and 0.7 % limb fixation. The authors estimate that only a small percentage of landmine/IED victims reached the hospital and that most victims died preclinically because of lack of first aid and transportation available, though no estimated numbers are named (108).

Another study in the civilian setting by Shabila et al. (2010), analysing 285 patients injured by landmines and reaching the Emergency Management Centre in Erbil, Iraq, stated that 48 % received first aid at a peripheral health care facility. This relatively high rate was mainly due to one first aid post 2 hours away from the hospital, which underlines the importance of functioning rural first aid posts (106).

Military personnel of the coalition forces in Afghanistan and Iraq are embedded in a preclinical chain for first aid and evacuation, called Tactical Combat Casualty Care (TCCC). This TCCC includes advanced first aid training for regular soldiers, TCCC trained combat field medics and rapid (air-)evacuation to field hospitals with surgical and resuscitative capabilities (113).

In recent years UK military casualties, injured in the Helmand province in Afghanistan or nearby, used to receive primary medical aid at Camp Bastion field hospital and were evacuated to the University Hospital in Birmingham. Critical Care Air Support Teams were able to repatriate intubated and ventilated patients right after initial resuscitative measures. Less severe cases were transported with the Aeromed system (105).

Early transportation into surgical facilities is key in landmine and IED victims. Singleton et al. (2013) showed that the mean time between injury and death in those dying from the blast and reaching the hospital is 80 minutes (81).

3.2.2 Tourniquet use

All UK and US military personnel, leaving the military base are equipped with windlass tourniquets. The windlass tourniquet is applied to the limb and tightened 30 mm by turning the attached rod. Effective haemorrhage control via the windlass tourniquet has been controversial. While some data shows an increase of the overall survival rate associated with the use of windlass tourniquets (114) others show failure of haemorrhage control (98). Taylor, Vater and Parker (2011) tested two tourniquet systems: the windlass tourniquet or Combat Application Tourniquet (CAT) (115), as described above, and the Emergency and Military Tourniquet (EMT) (116), a pneumatic tourniquet (98).

Figure 14 - Combat Application Tourniquet /windlass tourniquet (CAT)
Source: (115)

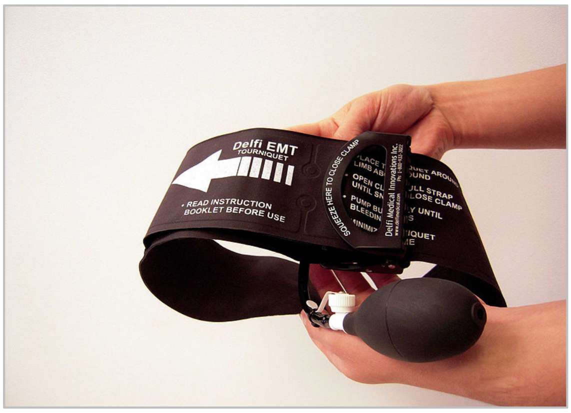

Figure 13 - Emergency and Military Tourniquet (EMT)
Source: (116)

Blood flow in the popliteal artery was evaluated with Doppler sonography and palpation of the pulse of the popliteal artery during the use of EMTs and CATs in 25 test persons. The test persons first applied the windlass tourniquet by themselves to their mid-thigh. Only 4 (16 %) showed a halt of the blood flow in the popliteal artery. The CAT (or windlass tourniquet) was then applied on the contralateral leg by a “trained researcher”, but only 2 (8 %) showed an occlusion of the artery. After this the EMT was applied to the mid-thigh. When using an EMT occlusion of the popliteal artery was detected in 18 out of 25 (72 %) patients. The study showed that CATs do not provide the desired haemorrhage control in the controlled setting. In the discussion, the scientist argued that one might think that CATs will be applied tighter in emergency rescue settings but that pain was not the limiting factor when tightening the CAT. Instead, the fabrication only allowed a tightening of 30 mm. The study therefore suggests the use of EMTs, which are available in compact versions with 220 gram, and that EMTs should be available to frontline medics and paramedics (98).

Singleton et al. (2013) found, in their paper on unexpected survivors of IED blasts, that bleeding from the low abdominal aorta or inguinal arteries was the second most common reason for exsanguination, which is the most common cause of death. The authors suggest the use of junctional tourniquets for preclinical haemorrhage control of pelvic bleeding (81).

The use of a tourniquet should be limited to 2 hours or a maximum of 6 hours. Crush syndrome is being reported in limbs which had a tourniquet applied for longer than 6 hours which made amputations proximal to the tourniquet necessary and renal failure more likely. In patients with tourniquets applied for 2 to 6 hours symptoms of crush injury should be expected. Forced diuresis to preserve good kidney function should be applied before removal of the tourniquet and fasciotomy of the adjacent compartments carried out (78).

3.3 Surgical management

All literature reviewed for this thesis agrees on three major principles for the surgical care of landmine and IED related injuries: 1) thorough debridement, 2) generous irrigation and 3) early start of antibiotic treatment. Thorough debridement is the most successful technique to avoid additional surgeries, extra days of hospital stay, infection and mortality. Debridement of soft tissue and bone fragments without attachment has to be radical and should include searching for necrotic tissue and foreign bodies along tissue planes way proximal to the apparent soft tissue wound. Skin and periosteum, on the other hand, should be debrided conservatively (4,78,83,87,88,92,97,104–108,111,112,117–120). Other aspects of the surgical care for these wounds are subject to different interpretations and routines, such as early amputation versus limb salvage, covering soft tissue defects, vascular control and osteosynthesis methods. In this chapter, different approaches will be discussed.

3.3.1 Surgical management of the limb

3.3.1.1 Surgical management according to the ICRC Approach

The Handbook *War Surgery. Working with limited resources in armed conflict and other situations of violence* Volume 2 of the International Committee of the Red Cross (ICRC) is the source for the following chapter on how the ICRC approaches landmine or IED related injuries to the limbs (78). The surgical care will be described in detail as an example for general surgical management of limb injuries (78).

Indication for surgical amputation in a humanitarian setting is not only determined by the severity of the injury but also by "availability of blood for transfusion, level of post-operative and physiotherapy care, accessibility of prosthesis and physical rehabilitation". General indications for surgical amputation are traumatic amputation of the limb, severe soft tissue damage with mangled or severely contaminated wounds, vascular injuries leading to ischaemic gangrene or compartment syndrome with necrosis of two or more compartments in one limb, damage control surgery (live before limb), uncontrollable haemorrhage or persisting chronic and painful infection (78).

When approaching a limb injured from a landmine or IED blast the mechanism of the injury must be kept in mind (for details see chapter 1.7 on Injury patterns). The injury extends to more levels than initially visible. The blast wave travels far along the tissue planes, along the periosteum and neurovascular bundles, dissecting the tissue and driving up debris. Necrosis and compartment syndrome should be reckoned with proximal to the visible bone and soft tissue injury. Superficial muscles are more likely to be intact than the deep structures, bones, muscles, vessels and nerves (78).

After initial resuscitation and primary survey following the ABCDE algorithm the patient is prepared for primary surgery. At ICRC facilities Ketamin is the most commonly used anaesthetic. Spinal anaesthesia can be used if resources are available and standalone local anaesthesia should only be used in exceptional situations. After sedation is initiated a thorough scrub down of the wound is carried out with water and soap. A pneumatic tourniquet is applied, with 50-70 mmHg above the normal systolic pressure of the patient, to provide temporary haemostasis. The tourniquet is either positioned on the proximal thigh for surgery on the lower extremity or proximal third of the arm for the upper extremity (78).

The procedure starts with conservative debridement of the skin and adequate skin incisions. All viable skin should be spared for delayed primary closure or as donor sites for skin graft. The "umbrella" (see chapter *1.7.2.5 Orthopaedic trauma* for details on the umbrella effect) is then opened by pulling soft tissue down and out, exposing proximal damage. Muscles are debrided following the 4 Cs: colour, consistency, contractility and capillary bleeding. Necrosis in deep muscles is usually encountered more proximal than in superficial muscles. In the leg the anterolateral compartment of the lower leg and the quadriceps are more likely to be severely injured than posterior compartments of muscle. Bone fragments without periostal attachment are generously removed but periosteum debrided conservatively. Besides avoiding exsanguination, debridement of necrotic tissue and loose bone fragments are the key factors that determine healing and complication rates. Major vessels can be repaired but should be covered with a local muscle flap if possible to avoid exposure. If vessel repair is not possible ligation is carried out. If necessary, damaged nerves and tendons are fixed to the surrounding tissue and cared for in a second surgery. Fractures can be temporarily stabilized or the bone amputated. Copious irrigation with 6 to 9 litres of normal saline in massive soft tissue injuries is another key factor. Specifics of amputation will be discussed below (78).

The wound is not closed, primarily because of the contamination of all war wounds. It is dressed with "bulky non-occlusive dressing of loose fluffed dry gauze and absorbent cotton wool" with an elastic bandage. The dressing stays in place for 4 to 5 days until delayed primary closure (DPC) unless signs of infection are identified. Smell does not necessarily indicate infection but can be due to the healing process (78).

In the worst case, with resources not allowing a second surgery, the limb can be splinted with an Orr-Trueta cast, a cylindrical cast without window, and the wound can heal by secondary intention. This will delay physiotherapy because the adjacent joints are immobilized as well (78).

For DPC the patient is sedated with Ketamin and the dressing removed. Bleeding contractive muscle is a sign for good viability. If temporary stabilization of the bone was performed in the primary surgery, definitive osteosynthesis can now be performed. The ICRC does not necessarily recommend sutures of the muscle, fascia or subcutaneous sutures. The skin is adapted with single interrupted sutures with generous space between sutures. If the wound shows signs of infection or necrosis, meticulous debridement is repeated with special attention to deep proximal necrosis and bone fragments without attachment to periosteum (78).

3.3.1.1.1 Amputation

The ICRC recommends either classical amputation surgery or myoplastic amputation, depending on the state of the wound or traumatic amputation, especially the extent of soft tissue injuries. In landmine- or IED-injuries superficial muscle groups are often intact whilst deep muscles and other deep structures are injured, making myoplastic amputation surgery a preferred option (78).

The level of amputation primarily depends on the level of soft tissue injuries. The most distal level that can be covered with a good unconventional muscle flap should be the level of amputation. At the end of primary surgery and amputation the skin and soft tissue should be approximated easily without tension. Disarticulation should be preferred to more proximal amputations in children whose growth plates are still open. However, disarticulation should be avoided in adults in settings with little resources, where access to necessary prosthetic care could prove difficult. In the case of damage control surgery in adults, disarticulation through the knee joint is preferred to transfemoral amputation (78).

3.3.1.1.1.1 Classical Amputation

As mentioned before all viable muscle and skin should be saved but necrotic soft tissue debrided generously and damaged skin and periosteum debrided conservatively. Most of the time the superficial muscle compartment is less damaged than the deep muscles and the posterior less than the anterior. Especially the anterolateral muscle compartment of the lower leg is usually subject to severe and proximal damage. At the end of debridement, the level of amputation is chosen as mentioned above, making adequate soft tissue coverage possible. In a classical amputation, the muscles are now cut obliquely across its fibres, which causes swelling of the muscles for several days. The swelling of the muscle makes DPC in these improvised stumps harder, which should be considered when planning DPC. The bone is sectioned with a Gigli saw and the edges are filed down. Damaged nerves are pulled gently and cut off with a fresh knife in the second surgery. Crushing or fraying of the nerve with forceps, scissors or a blunt scalpel should be avoided to reduce the risk for residual limb or phantom limb pain. When releasing the nerve, it snaps back into the surrounding soft tissue, this avoids neuromas on the stump (for details see chapter *3.6 on Postoperative pain)* The stump is dressed as described before and closed in a second surgery at delayed primary closure (78).

3.3.1.1.1.2 Myoplastic amputation

The myoplastic amputation is often suitable for landmine and IED injuries due to the umbrella effect (see chapter *1.7.2.5 Orthopaedic trauma* for details on the umbrella effect) and the relatively good viability of superficial muscle.

The patient is prepared as mentioned before and thorough debridement carried out, but debridement of superficial muscles should be conservative. Superficial muscles are mobilised including their fascio-cutaneous surroundings and the tendon at the distal insertion cut loose. This prevents the muscle swelling seen in classical amputations. The muscles most commonly used as soft tissue coverage in myoplastic amputations in the lower extremity are the soleus muscle and the medial gastrocnemius muscle for lower or mid tibial amputations and the vastus medialis muscle for above knee amputations (78,88,91).

3.3.1.2 Addition to the surgical care of limb injuries

In the following chapter the general principles of surgical care for landmine and IED injuries, as discussed in the previous chapter, will be further analysed and complemented by additional literature. The following literature was written by authors working with data from civilian or military hospitals.

3.3.1.2.1 Amputation level

According to Keklikçi, post-traumatic vessel disease (PTVD) should be kept in mind when planning the transection of viable muscle, as the remaining muscle should ideally lay proximal of the level of PTVD. The shock wave leads to fissuring of the tunicae intima and media in proximal parts of the limb (120).

3.3.1.2.2 Osteosynthesis

The ICRC handbook discourages the use of intramedullary osteosynthesis in war wounds in general, and the primary treatment of fractures in low resource settings in particular because of a high reported osteomyelitis rate (78).

Wagner et al. (2015) treated 10 patients with traumatic lower extremity amputations from IED blasts with secondary retrograde intramedullary fixation. 5 patients had transfemoral amputations, 4 had knee disarticulations and one patient had a Symes amputation. The fractures were initially stabilized with monolateral external fixation. After an average of 6 surgical debridements and irrigations, or 11.7 days, the patients underwent retrograde intramedullary fixation through the amputation site. Traction and control was applied to the distal fragment with a Weber tenaculum or a wire and bow to avoid further damage to the bone. No special attention was given to rotational deformities. There was no infection of the fracture or implants noted. Osseus union was 7.5 months and heterotopic ossification (HO) was seen in 8 patients, 3 of whom required revision of the HO. Rotational deformities in the patients was observed, even though no specific number of affected patients is mentioned. The overall satisfaction with intermedullary fixation was similar to other techniques of osteosynthesis. 1 of the 10 patients had an infection due to surgery but it was superficial and did not affect the bone (121).

Tahir Khan et al. (2002) report of a case of reconstructive surgery after a hindfoot injury from an IED blast. The fracture was stabilized with a AO-type external fixator and supplemented with intermedullary rush rods and Kirschner wires including a arthrodesis of the inter-tarsal and ankle joints (111).

3.3.1.2.3 Wound Dressing

Standard wound dressing, used by the ICRC and commonly used in civilian settings, consist of soft dry gauze and cotton wool, which absorbs the exudate, and a firm bandage around it. The dressing is usually left on the open wound until delayed primary closure. The only reason for opening the dressing before DPC are signs of infection of the open wound. (78)

A couple of studies compared this standard wound dressing to special or modern wound dressings. Fries et al. (2014) compared the standard wound dressing to a nanocrystalline silver dressing called Acticoat™. 76 patients who sustained injuries due to IEDs, which are by their nature heavily contaminated, were included in the study. 39 received the standard dressing and 37 received the silver dressing after surgery. Both groups received 1.2 g co-amoxiclav every 8 hours. The wounds were then assessed in terms of bacterial colonialization, smell and time for wound healing in 65 cases. Assessment showed no significant difference between the two groups regarding the number of wounds that were contaminated with bacteria, the number of dressings that were colonised with bacteria or the kind of bacteria detected. Also, the number of dressings leaking exudate was similar in treatment and control group. The silver dressing did show advantages over the standard dressing regarding the smell, which contributed to the wellbeing of the patients. Fries et al. are concerned about the strikethrough rate of exudate through both types of wound dressing. They suggest that further investigation towards topical negative pressure dressings (TNPD) in war wounds should be done. (122).

The ICRC voices concerns about the use of TNPD because of reports of persisting infections of war wounds dressed with TNPD. They recommended further investigation, specifically in the use of TNPD in war wounds (78).

Multiple studies show a positive effect on wound healing through the use of TNPD. Local wound hygiene is improved and revascularisation promoted (117,119,123).

3.3.1.2.4 Frequency and regional distribution of amputation

Shabila et al. (2010) detected a high incidence of traumatic or necessary surgical amputations in their 285-patient cohort. A total of 71.9 % of the patients had one or more limbs amputated. The most common amputations were below knee amputations (30.5 %), followed by foot amputation (20.0 %) and hand amputation (25 %). Fingers were amputated in only 0.7 % and toes in 2.5 %, suggesting that the explosive force was severe (106).

3.3.1.2.5 Social acceptance of limb amputation and prosthesis

In their 2002 paper on the surgical care of pattern 1 injuries in Pakistan, Tahir Khan et al. argue that limb amputation and prosthetics lead to a social stigma for the affected people. “An amputee would be considered as a burden on the family and society as a whole” in communities which are based on agriculture and self-sufficiency. Patients who came for a follow-up in this study argued that they were not able to wear them because of “hot weather, social taboos and geographical terrain”. None of them was satisfied with the prosthesis (111).

3.3.1.3 Limb Salvage

The decision for or against limb salvage is closely linked to the severity of the injury but also the availability of resources, in terms of surgical specialists and medical equipment.

Tahir Khan et al. (2002) describe the surgical care for 28 male patients between the ages of 13 and 55. 6 of those patients reached the hospital within 24 hours and for 4 it was possible to salvage the foot. The other 22 patients received a below-knee amputation (111).

The 4 patients for whom limb salvage was possible had similar wound patterns. All had a severely damaged talus and calcaneus but intact soft tissue and neurovascular bundle on the dorsal portion of the foot. With the dorsalis pedis artery intact, the capillary return on the foot was good (111).

All 4 patients were showing clinical signs of shock when reaching the hospital and were resuscitated with blood transfusion, i.v. fluids and prophylactic antibiotics. The wounds were radically debrided and initially stabilized with an AO-type external fixator. The viability of the foot was then revaluated and proved satisfactory. The stabilization was then supplemented with intermedullary rush rods and Kirschner wires including an arthrodesis of the inter-tarsal and ankle joints. The viable skin of the foot was used for a split thickness skin graft. The 4 patients had between 6 to 10 surgeries in total at the time the study was conducted. Two more surgeries were planned at that time. The patients in this cohort were unwilling to wear prosthesis because of social and cultural stigma, so patients receiving limb salvage were more satisfied than those receiving amputation (111).

Demiralp et al. (2013) report a 24-year old male who sustained pattern 1 injuries from kneeling on a landmine. The patient suffered a loss of the patella, a 20 cm long bone defect of the distal femur and proximal tibia, bone loss of the proximal fibular, damage to the patellar tendon, quadriceps tendon, anterior muscle groups of the upper and lower leg and damage to the peroneus nerve. The popliteal neurovascular bundle as well as the tibial and femoral arteries were intact. The injury was categorised a Gustilo-Anderson type III-C (see chapter 2.8.1.3) injury with a Mangled Extremity Severity Score (MESS) of 6. It was decided to attempt limb salvage (124).

In the initial surgery, the damaged soft tissue, bone and bone fragments were debrided and irrigated, an external fixator applied and temporary skin graft performed. In the following 2 weeks, the wound was irrigated and debrided every 48 hours, surgical debridement was necessary 4 times. The patient was given tetanus prophylaxis, 1 g cephalosporin (1-0-1 over 5 days), 250 mg ornidazole (1-0-1 over 5 days), 80 mg aminoglycoside (1-0-1 over 2 days) and 60 mg enoxaparine s.c. for medication information) daily. A free latissimus dorsi flap was performed by plastic surgeons. In the following 4 surgeries the length of the leg was corrected with multiple osteotomies resulting in a 2 cm length discrepancy (124).

Jaha et al. (2012) performed surgery on 120 patients with vascular injuries, 10 of which were injured from a landmine. The group describes successful vascular surgery but points out that complex vascular injury, with injuries not only to the arteries but also to the surrounding veins, nerves and bones, delays repair or prolongs reconstructive surgery. The delayed repair leads to tissue ischaemia and therefore higher morbidity and longer surgery, leading to an increased infection rate and poorer functional outcome. All patients who presented with vascular injuries due to landmines had complex vascular injury. In consequence, it can be interpreted that vascular repair, in injuries caused by landmines and IEDs, will cause tissue ischaemia, a higher infection rate and poorer functional outcome. Nevertheless 4 of the 10 patients received vascular reconstructive surgery, 2 received an autologous venous graft, 1 a lateral suture and 1 an end to end anastomosis (125).

Keklikçi et al. (2010) describe the case of a 20-year old male who was injured by a landmine. He sustained a traumatic amputation of the right leg, severe soft tissue injuries and fractures to the left leg and a degloving injury to the left forearm. The left had no vascular injury but only degloving injuries to the knee as well as ligament instability of the knee. It was possible to salvage the left leg (120).

3.3.2 Surgical care for perineal and genitourinary injuries

Moussadegh et al. (2012) report on pelvi-perineal injuries in 118 military patients. They defined a couple of surgical recommendations for those injuries: Initial debridement and sequential debridement have to be thorough and aggressive. Irrigation of the wound is also necessary. 21 % of all complications in the patients were due to remaining foreign bodies, which should be avoided with aggressive debridement and irrigation. Faecal diversion can be helpful in preventing further infections and decrease mortality (97).

Exsanguination following massive haemorrhage is the most common cause of death in patients with pelvic fractures. Pelvic sheeting provides good temporary haemorrhage control but external fixation is necessary before pelvic packing to stabilize the pelvis. Cross clamping of the aorta or occlusion of the aorta with a balloon catheter might be necessary in patients with massive bleeding from the pelvic fracture as a first resuscitation method (97).

The authors advise to wrap injured gonads in Vaseline gauze and moist swaps until a specialised urological surgeon is available. The creation of a thigh soft tissue pocket is not advised according to this study because of the compression of the epididymis and vas deferens. Tight wrapping in gauze is therefore also not advisable (97).

There is some evidence that amputation of both testicles and the decreased testosterone production in consequence, lowers mortality, because testosterone is known to supress immune functions. But bilateral amputation should of course not be carried out if not necessary (97).

As mentioned above, Banti et al. (2015) found scrotal trauma to be the most common genitourinary (GU) injury in their patient cohort, making up 39 % of GU trauma (4). Williams et al. (2013) also recorded a high percentage of scrotal injuries, making up 15 % of all GU trauma in their study. IEDs or landmines caused 89 % of them. Williams et al. describe surgical management of scrotal and testicular injuries in Iraq and Afghanistan between 2003-2009. This study period ended before a spike in IED and landmine related

GU injuries between 2009-2011 (4,97) and therefore includes only 27 patients. 11 patients (40 %) suffered traumatic orchiectomy, 4 of them bilateral. The authors emphasise restraint concerning surgical orchiectomy and radical debridement in those injuries. If possible preservation of viable spermatozoa should be performed. They proposed an algorithm to facilitate surgical decision making in scrotal and testicular trauma. Patients with isolated scrotal injury should be debrided, primary closure with a drain or dressing or delayed primary closure should be pursued if enough tissue for covering the defect is viable. If the tissue defect is too big, a dressing, the authors used Jelonet® (see Annex for further information), is applied and the patient is transferred to a specialised department. In this department, reconstructive surgery, following the reconstructive ladder, ideally using skin graft is advised. If a combined scrotal and testicular injury is encountered, testicular ischaemia should be ruled out, the wound reluctantly debrided, the tunica closed with interrupted sutures or a dressing applied. If the combined injury presents with testicular ischaemia due to cord transection, orchiectomy has to be carried out. Especially if bilateral orchiectomy is necessary, this should follow extraction and preservation of spermatozoa (112).

3.3.3 Surgical care for visceral injuries

Ozer et al. (2014) report on a case of a 22-year-old male who sustained injuries to his inguinal region and left leg from an IED. The patient showed injuries to the bladder, membranous urethra and left iliac artery and vein. The rectum showed areas of impaired circulation but no perforation. The surgeons decided to perform sigmoid diversion to prevent contamination of the injured intrapelvic organs. A cystostomy, bilateral ligation of the internal iliac artery, a iliofemoral bypass and the placement of a Foley catheter between the membranous urethra and prostate were performed. The bilateral ligation of the internal iliac artery was undone, due to hypoperfusion of the penis and scrotum. On the 5th postoperative day the left leg had to be amputated with a disarticulation from the hip joint. On the 8th day after the blast incident the amputation-site on the left leg presented with “foul-smelling purulent leakage” and a perforation of the rectum was discovered. The authors suspect vascular endothelial injury via the blast wave with the effect of ischaemia of the rectum and therefore the delayed perforation. Because of the bad general condition, the patient was in at this moment, extensive surgery was avoided but a self-expanding covered stent (SECS) was inserted into the rectum, the leakage thereby sealed and the stent secured with sutures to the anal verge. A foam based topic negative pressure dressing (TNPD) was applied to the wound on the left leg and changed every third day. When the

SECS was removed in the 3rd week after the injury, the rectum perforation had healed completely. In week 4 the urethra was reconstructed. A colonoscopy 10 months post injury showed a well-healed rectum. The use of SECS in combination with TNPD in this patient was successful, but no other case have been described so far (117).

3.3.4 Surgical care for craniofacial injuries

A mean of 27.3 % of landmine or IED victims sustain injuries to the head, neck or face. Because of its rich vascularisation, maxillofacial injuries can cause violent haemorrhage, thereby compromising the airway. Early control of the bleeding is therefore essential. Shuker (2011) described the urgency of airway control by intubation or a surgical airway and vascular control with the use of Foley catheter balloon tamponade, digital pressure, visible clamping, wet gauze packs to avoid air embolism and ligation. He found that the use of a Foley catheter had a good success rate and that it can be used for acute management until the vessel is ligated or as conservative treatment for the vessel injury for 7-10 days. He used conservative treatment with Foley catheter in 6 out of 7 successfully treated patients (126).

Brennan addressed the topic of head and neck trauma in a 2013 paper, comparing head and neck trauma in Iraq and Afghanistan. He describes the surgical care for 142 patients, mostly military personnel. The most common surgeries performed in those patients were facial laceration repair in 28 %, surgical airways in 19 %, open osteosynthesis of facial fractures in 16.5 %, intermaxillary fixation in 11 %, neck exploration in 4 % and oral tongue laceration repair in 1.6 %. Brennan describes immediate primary closure after "extensive irrigation and conservative debridement". A commonly seen injury was the mandibular fracture in which functioning occlusion of the teeth was the main goal. (127)

Another publication that stresses the importance of immediate and aggressive airway control and management of bleeding is from Gallo et al. (2009). This paper reports a case of an IED victim who had an emergency cricothyrotomy, which was occluded with blood due to massive bleeding (128).

3.3.5 Haemorrhage control

Poon et al. (2013) analysed operative control of haemorrhage in 51 patients with proximal traumatic lower-extremity amputations. Those amputations are associated with a high mortality because of iliofemoral and pelvic bleeding. 41 patients had intraperitoneal proximal vascular control and 10 patients had extraperitoneal vascular control. Of those undergoing intraperitoneal vascular control the intervention itself was the primary indication for the laparotomy in 46.3 %. 29.3 % had diagnostic laparotomy because of haemodynamic instability and 24.6 % had suspected intra-abdominal injuries. For those receiving intraperitoneal arterial control bilateral control was performed in 73.2 % and the common iliac artery was the most common position with 58.5 %. The external iliac artery was clamped in 70 % of the patients who had extraperitoneal vascular control. The authors deem surgical vascular control necessary for 1 in 5 patients with proximal amputation of the lower extremity (129).

3.3.6 Covering soft tissue defects

3.3.6.1 Grafts

Split thickness skin grafts are regularly used to cover soft tissue defects in wounds caused by landmines or IEDs. Free fillet flaps are more demanding for surgeon, resources and especially the patient. Therefore, this technique is not as frequently used in landmine and IED injuries. Sherman et al. (2006) argue that timing for grafts or muscle flaps is essential to avoid complications like infection, rehospitalisation and problems of wound union. They carefully recommend early wound coverage within the first 7 days, with whatever technique, but point out that further investigations are necessary (118). Kumar et al. (2009) speak of an even shorter timeframe and argue that no longer than 72 hours should pass between injury and wound coverage with a flap (123).

The disadvantage of a skin graft is, that it can't be placed over exposed bone, tendon or osteosynthesis. A study by Foong et al. on the use of Integra™, an artificial skin graft, in a small group of patients showed good results in 2013. 7 patients injured by an IED received either a single- or bilayer Integra™ graft for 11 wounds, as soon as the wound was considered to be clean. Before the application, patients underwent a mean of 5 trips to the theatre for surgical debridement, irrigation of the wound and the application of a topical negative pressure dressing (TNPD). The application of the artificial graft took place between the 6^{th}-24^{th} day after the injury was sustained. Integra™ was first soaked in a suspension of Amphotericin and Ciprofloxacin, meshed 1:1, applied to the defect and secured with staples. To further secure the artificial graft and to promote wound healing a TNPD was applied. Vascularisation of the graft was achieved in between 7 and 31 days. At that point delayed split thickness skin grafting was performed and TNPD applied again. Single layer use of Integra™ led to earlier vascularisation. 3 out of 11 wounds did not take Integra™ satisfactory. One patient had 2 wounds of which one did not take the artificial graft at all and the other wound vascularised only 50 % due to infection. Another graft was taken only 65 % over the Achilles tendon, which possibly led to shearing. In other wounds coverage of tendon, bone and metal was successful. The authors claim that the use of Integra™ and delayed split thickness skin grafting leads to an end result with more durable and elastic skin cover, suitable for the high demand of young amputees using prosthesis. The two-stage approach with delayed split thickness skin grafting does delay treatment and prolongs hospital stay (119).

3.3.6.2 Free-fillet Flap

A free-fillet flap is defined as a "composite axial flap[s] that may provide skin, muscle, fascia and bone" and are sometimes used to cover soft tissue loss in landmine or IED injuries (120). Thickness of those flaps depends on the soft tissue defect. Kumar et al. (2009) used musculocutaneous flaps for primary reconstruction of large defects, fascioucutaneous flaps in smaller vascularized tissue and adipofascial flaps in small and relatively superficial wounds (123).

Foong et al. (2013) stress the importance of the conservation of upper body strength for bilateral amputees of the lower extremity. People with bilateral amputations to the lower extremity require extra strength in the upper body to use crutches, stabilize the torso when walking with prosthesis or pushing their wheelchair. To use the latissimus dorsi, rectus or gluteus maximus muscle is therefore not advised in bilateral amputees (119).

A case report of a 20-year-old male who suffered a pattern 1 landmine injury was published by Keklikçi et al. (2010). The patient suffered a traumatic below-knee amputation to the left leg, a radius fracture and degloving injury on the right forearm and an extensive soft tissue injury to the left leg. The left leg presented with an open tibial fracture, proximal fibular fracture, a circumferential degloving injury of the knee with ligamentous instability and a crush injury of the distal third. The posterior muscle compartment and neurovascular bundle of the right leg was viable proximal to the traumatic amputation. The anterior compartment and anterior tibial vessel were not salvageable. The posterior muscle group of the amputated right leg was used for a free-fillet flap to cover the degloving injury to the right forearm. After debridement, an 18x12 cm flap was determined suitable for a fillet-flap transfer and dissected together with the posterior tibial artery and an associated vein. The receiving site was thoroughly debrided and irrigated as well. The vessels were anastomosed end to end with the radial artery and cephalic vein and the fillet-flap sutured in place (120).

The authors point agrees with many other publications that thorough debridement is the most important aspect of the surgical care for landmine and IED injuries (4,78,83,87,88,92,97,105–108,112,117–120). The benefit of the fillet flap lies in better infection control and functional recovery, as well as a shorter recovery time in the receiving site, fewer operations and better acceptance of the injured limb by the patient. In this case the use of the posterior muscle compartment of the amputated leg prevented additional donor-site morbidity (120).

3.4 Antibiotics

The ICRCs antibiotic protocol recommends the following antibiotic regime for anti-personnel landmine or IED injuries: immediate i.v. administration of Penicillin-G 5 MIU QID and metronidazole 500 mg TID. Oral antibiotics are started 48 hours after the injury until the delayed primary closure (DPC) of the wound, which usually occurs after 4 to 5 days after initial surgery. Oral antibiotics administered are Penicillin-V tablets 500 mg QID and Metronidazole tablets 500 mg TID. If the DPC is performed with a split skin graft, Penicillin-V tablets 500 mg QID are administered for 5 more days after DPC. If a systemic or active local infection is apparent, Penicillin-V tablets 500 mg QID are continued, Metronidazole 500 mg TID is administered intravenous and Gentamycin 80 mg i.v. TID is given additionally (104).

According to Gustilo et al. (1976) it is traditionally recommended to give i.v. antibiotics to all patients with open fractures. Gustilo Type III injuries require 3 different antibiotics. Gram positive bacteria contamination is treated with 1st generation Cephalosporin. Gram negative bacteria contamination is treated with Aminoglycoside. Anaerobic bacteria contamination is treated with penicillin. Antibiotics should be given 24-72 hours after the last debridement of the wound (89).

In a 2011 publication Sherwood et al describe a case report of a 23-year-old who was injured in an IED blast and exposed to water with raw sewage. The bilateral open tibia and fibula fractures were debrided and irrigated and the patient initially given Carbapenem. The treatment failed to eradicate the Baceroides fragilis contamination and the treatment changed to Metronidazole. A Tigecycline was added when Metronidazole showed no success. Eventually susceptibility testing was carried out. The treatment regime was changed, the wound was surgically debrided again, “aggressively irrigated” and Moxifloxacin and Linezolid were given for 8 weeks. This treatment was eventually successful. This case report emphasises the importance of individualised antibiotic treatment, even in settings with limited resources (130).

In their study on nanocrystalline silver wound dressing Fries et al. gave 1.2 g co-amoxiclav every 8 hours (122).

Mossadegh et al. (2012) also describe massive contamination of IED injuries. Even after debridement and irrigation bacterial and fungal contamination was found in 63 % of the cases. The paper recommends early start of antibiotic treatment, within one hour. Though a specific antibiotic therapy is not named, a routine culture of the wound, with a sample taken after initial debridement, is advised by the authors (97). It should be kept in mind that bacterial cultures need some days to incubate and will not show results right away.

3.5 Pre-prosthetic rehabilitation

After secondary surgery and the closure of the limb, an elastic bandage is wrapped around the limb to tame it for the use of prosthesis, and the limb should be elevated when resting. Joint contractures should be prevented with early physiotherapy and the regaining of a full range of motion, in order to prepare the stump for the prosthetic limb. “Isometric exercises and progressive resistive exercises should be done on all limbs to maintain and strengthen muscles necessary for the rehabilitation process, crutch walking, ambulation, and a prosthetic limb”. The patients should be mobilised as soon as possible to prevent effects of a long bed-rest, like thrombosis or a decrease of strength and cardiovascular fitness (78,109,123).

3.6 Postoperative pain

Postoperative pain in amputated limbs can be categorised in phantom limb pain, residual limb pain and neuroma pain. Wiffen et al. (2006) assume that 30 % of all patients with amputated limbs have phantom limb pain. It is suggested that good analgesia during and after amputation surgery are key to avoid the occurrence of phantom limb pain. “Phantom limb pain (PLP) is by definition neuropathic” and therefore not sensitive to NSAIDs. Tricyclic antidepressants of 25-150 mg/day and anticonvulsants, like carbamazepine, sodium valproate and phenytoin, seem to provide the best pain relief for phantom limb pain. (131). Neuroma pain is best prevented with careful surgery (110,131). Nerves should never be crushed with forceps, clamps, retractors or a blunt blade or scissor and should be shortened in a manner that the end of the nerve lies buried in soft tissue. The nerve is therefore carefully pulled upon and cut with a sharp and new blade. If a neuroma occurs, it can be diagnosed but not treated with a local nerve block with local anaesthetics. The term residual limb pain includes a wide range of painful complications from the initial injury, amputation surgery, pain from the prosthesis or hyperalgesia or allodynia that became chronic. NSAIDs are helpful in the treatment for residual limb pain but many times the WHOs treatment regime for chronic nociceptive pain has to be consulted (131).

3.7 Community-based medical care

Due to the fact that conflict zones are often inaccessible for international humanitarian NGOs and official governments many times neglect medical care as well, some community based organisations (CBO) for medical care have formed.

One example is the Trauma Management Program (TMP) in eastern Myanmar. Over 300 health care workers received training, making medical care for 250,000 internally displaced people possible. The training ranges from a 4-day to an 18-month course and from a first-responder health training to a train-the trainer course for more experienced health care workers. In the more advanced courses health workers with prior trauma training are taught resuscitation, stabilization, management of haemorrhagic shock, wound care, control of bleeding, fasciotomy, amputation, fracture and dislocation management, splinting and casting. The TMP also provides the most necessary equipment to treat patients, like stethoscopes, gloves, amputation saws and tourniquets. A study by Allison et al. from 2009 analysed 200 patients treated by local health workers. Of the 200 patients 88 (44 %) were injured by landmines. Fasciotomies and amputations were performed under Ketamin sedation, blood transfusion was performed, antibiotics given and the affected limbs were splinted with plaster or locally available bamboo. In this study 9 % of landmine victims survived, but initially diseased victims were not counted. Data from before the courses were initiated in 2000 are not available. It is therefore not possible to tell the quantitative effect from the training of health care worker on morbidity and mortality (132).

The necessity of local clinics or community-based first aid becomes apparent when reading about the availability of qualified first aid in areas affected by landmines and IEDs. Shabila et al. (2010) recorded that 108 out of 285 patients (38 %) needed 6 hours or longer to reach the hospital. 148 (52 %) out of those 285 patients received no qualified first aid (106).

4 Discussion

“He who would become a surgeon should join the army and follow it," – Hippocrates

Fortunately, he or she, who will become a surgeon, doesn’t have to adhere to this more than 2000-year-old advice, as today there are many non-military organisations specialising in treating victims of war. Also, much can be learned about the surgical care for war wounds from recent civilian, humanitarian and military publications. Unfortunately, the quality of care, reported in these publications, can only be provided for a few. And even for them resources in times of armed conflict often only allow for basic surgical care. But because of the high prevalence of injuries caused by explosive blast in war surgery, any surgeon confronted with blast injuries can draw lessons from these studies.

The analysis of 65 publications from the civilian and military setting, as well as a handbook on war surgery from the ICRC, has confirmed the most important aspects of the surgical care for injuries caused by anti-personnel landmines and IEDs agreed upon by all caregivers. Aggressive debridement, copious irrigation and haemorrhage control are the most crucial aspects of therapy (4,8,78,83,87,88,92,97,104–108,111,112,117–120) and early start of antibiotic treatment has a significant positive effect on survival (89,97,104,122,130).

Other aspects of resuscitation and surgical care remain subject to a more controversial discussion.

4.1 Preclinical management and haemorrhage control

The importance of fast and effective evacuation for victims of landmine or IED explosions, to reduce in-field mortality, is obvious (81,105,106,108,132). C-spine immobilisation seems appropriate in pattern 1 landmine or IED injuries, even though the main difficulty seems to be the assertion of the implementation of immobilisation guidelines (110).

The importance of early preclinical haemorrhagic control using a tourniquet is undisputed but, as described in *chapter 3.2.2 on Tourniquet use*, studies show different effectiveness of the various models. One study by Taylor et al. (2011) comparing a windlass tourniquet (CAT) and a pneumatic tourniquet (EMT) show very low success rates with the CAT achieving haemorrhage control in the lower leg in only 16% and the EMT in 72%. This study conflicts with the findings of Guo et al. (2011) which showed a success rate of 100% for the leg with both a pneumatic and a windlass tourniquet. Even an improvised tourniquet, using a belt, showed a success rate of 60% in this study (133). Because of the more devastating injuries, caused by higher amounts of explosives in IEDs, junctional tourniquets are becoming more important (3,4,97). Kragh et al. (2014) compared four models of junctional tourniquets. Three of those control haemorrhage by compressing the communal iliac artery and one model by compressing the low abdominal aorta. The three similar junctional tourniquets had success-rates of 87 %, 77 % and 77 % after 60 seconds. The junctional tourniquet compressing the abdominal aorta was painful and therefore successful compression was achieved in only 27 % (134).

In summary, the two main goals of preclinical management should be rapid evacuation and sufficient haemorrhage control, and therefore the use of windlass or pneumatic tourniquets.

4.2 Resuscitation

Another limiting factor distinguishing the setting with good from the setting with scarce resources is the use of blood products. The analysis has shown that landmine and IED victims need high amounts of blood products (4,78,97,104,111,132). The UK and US military guidelines suggest the use of PRBS, FFPs and platelets in a ratio of 1:1:1 with good outcomes (135). For smaller military hospitals as well as humanitarian and civilian hospitals the availability of blood products is a limiting factor for surgical care (78,104).

4.3 Surgical care

While many military publications suggest sequential debridement, for example every 48 hours, the ICRC and civilian publications argue that a single surgery for debridement should be performed and the dressed stump left untouched until DPC after 4 to 5 days (78,96,97,105,112,118,121,123,124) .

The decision for surgical amputation or limb salvage depends as much on the specific wound presenting as it does on the available resources, in particular in terms of specialised surgeons and rehabilitation facilities. Limb salvage should always be considered and the limb should be evaluated using the Mangled Extremity Severity Score or others like the Bastion Classification (78,87,111,124). Social and cultural reservations towards amputation and the use of prosthesis have to be considered (111).

4.4 Antibiotic therapy

As mentioned above, the early start of antibiotic treatment is a key factor in reducing morbidity and improving the long-term outcome. Even though no specific substance was agreed upon in the reviewed literature β-lactam antibiotics and Nitromidazole were the most commonly combined substances (89,97,104,122,130). The early start of antibiotic treatment, as early as possible, has been especially emphasized by Mossadegh et al. (97) and can be supported by a review paper from Grote et al. (136). This review paper on antibiotic treatment for open fractures recommends parenteral Cephalosporine (or Clindamycin if the patient is allergic to Cephalosporine) and Aminoglycoside for Gustilo III injuries and additional high doses of Penicillin in contaminated wounds. The authors recommend treatment with the combination of those two or three antibiotics for at least 72 hours after delayed primary closure (136). Dunkel et al. found in their retrospective case-control study that antibiotic treatment for more than one day has no significant advantage to one-day long treatment, pointing out that their patient cohort did not include injuries caused by explosive blast (137). This opinion is shared in the ICRC handbook, emphasising that single-dose or antibiotic treatment for one day only can be sufficient only in settings with "optimal conditions of rapid evacuation, early pre-hospital first aid, [sic!] and adequate infrastructural hygiene" (104).

4.5 Conclusion

The analysis of 65 publications from the civilian and military setting, as well as a handbook on war surgery from the ICRC has produced the following findings:

Preclinical management, if available, has to focus on rapid evacuation and haemorrhage control using a windlass or pneumatic tourniquet.

The most effective aspect of surgical care for landmine and IED injuries are aggressive debridement and copious irrigation. Both are relatively cheap and can be carried out by general surgeons or trauma surgeons without necessarily needing additional training.

Another key factor to survival and low morbidity is the early start of antibiotic treatment. A combination of beta-lactam antibiotics, penicillin and aminoglycoside or nitroimidazole should be started as soon as possible.

4.6 Limitations

It was possible to isolate a few key factors of surgical management, which are agreed on by authors from the three different areas. Nevertheless, it is possible that the meta-analysis does not cover all publications on the surgical care for injuries caused by anti-personnel landmines and improvised explosive devices because of restricted access or missed publications. It was not possible to conduct quantitative reviews for many aspects because of methodical discrepancies in the various publications (e.g. studies that are impossible to compare because of their use of differing age groups).

4.7 Recommendations for future research

A comprehensive analysis of original data from civilian, humanitarian and military hospitals in Afghanistan from 2001-2016 on surgery for landmine and IED injuries would be of benefit. Comparing the number of surgeries required, time in theatre, time between primary surgery and DPC, blood products administered and in-hospital mortality could offer useful insights for future surgical care.

Furthermore, a comprehensive analysis of in-field mortality from landmines and improvised explosive devices has not yet been conducted. To know in-field mortality is crucial to be able to interpret in-hospital mortality. Further research is advised.

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