14 Terror-Related Trauma

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14.1 Preface

In our current era, terrorist attacks have become a part of our daily life experience almost worldwide. New terrorist groups are emerging and the number of terrorist attacks is constantly rising.

There are many definitions of terror, all of which are influenced by the individual viewpoint of the person defining them – a person could be declared a terrorist by his enemy, but in his own eyes, he is a "freedom fighter," The basic definition of terrorism states that terrorism is "a modus operandi in which deliberate violence against civilians is used for the purpose of achieving political goals" [1].

The delegitimacy of the terroristic act derives mainly from the violence towards civilians and not from the political cause on which behalf it was committed. In addition to that, this definition separates violent acts carried out against soldiers from violent acts carried out against civilians, though the means are sometimes inseparable. The terroristic act could be motivated by a political cause, economical cause, national cause and – maybe the most dangerous one – an extreme religious cause. The most outstanding example of the last two decades would be the terroristic organization founded by Osama bin Laden in 1998 – "the Islamic front for Jihad against Jews and Crusaders" or better known as Al-Qaida, who declared that every Muslim must fight US citizens all over the world [2] including their soil, as was committed by the September 11, 2001, attack on the twin towers in New York and the Pentagon in Washington DC. It was that attack that changed the world's perception and response to terrorism.

A large-scale terrorist attack such as the attack of 09/11 in New York is defined as a mega-terroristic event [3], mainly due to the enormous amount of casualties per single event; however, suicide bombers and car bombs are those events that cause the largest number of casualties worldwide. The terrorists understood that it is very difficult to stop a very motivated lone terrorist from achieving his goal and are thus focusing their efforts in that direction.

The suicide bomber was first introduced to the Middle East in 1983 by the Hezbollah terror organization [4]. On October of that year, two suicide bombers exploded in Beirut, killing 241 Americans and 58 French people and demonstrated the lethal effect of that weapon. Later they claimed that it was that attack which drove the American

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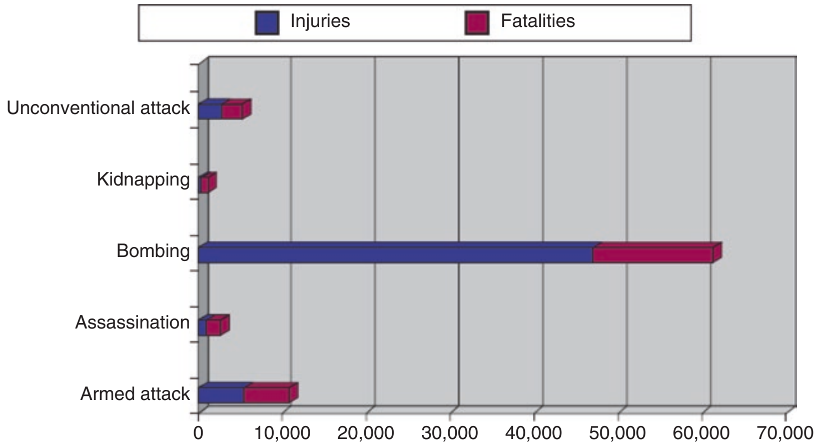

Fig. 14.1 Injuries and fatalities from terrorist incidents, 1998–2005. Data from the RAND-MIPT Terrorism Incident Database show that bomb blast injuries account for 82 % of all injuries caused by terrorists. (Available at: http://www.tkb.org/incidenttacticmodule.jsp.)

and French forces out of Lebanon. Over the next 17 years, the same organization committed dozens of similar attacks in an attempt to force the IDF out of Lebanon as well. The "success" of these attacks was later taught by the Hezbollah terrorists on to Palestinian terrorist organizations, which started their own deadly campaign on Israeli civilians in 1993. Between the years 2000–2006, they launched over 150 suicide attacks in Israel, taking the lives of hundreds and injuring thousands of civilians [5].

The effects of terroristic acts are economical, social, and political and of course have a tremendous effect on the health system. As these events became more and more common, health professionals worldwide realized the need to treat large masses of casualties at once. In facing the difficulty, different techniques were developed to overcome that need, most of them were developed in Israel due to the unfortunate vast experience of its medical teams in coping with such events [6].

In this chapter, we will discuss the different mechanisms of injury in different terroristic events, elaborate on the issue of triage, and finally talk about treatment options regarding typical injuries of such attacks.

14.2 Mechanism of Injury

When trying to describe the different mechanisms of injury, it is accustomed to divide them into two large groups according to the weapon used – conventional and unconventional [7]. Within the unconventional terrorism group, one can find chemical terrorism, biological terrorism, radiological terrorism, and lately cyberterrorism [8]. A number of different mechanisms can be found within the conventional group, such as firearm shooting, shrapnel, stabbings, stone castings, deliberate motor vehicle crushing, and, of course, blasts.

In the geopolitical atmosphere of our times, and specifically in the Middle East, great attention is given to the unconventional weapons group, while in fact the number of terroristic events that these weapons were involved in is very low. The largest amount of casualties is ultimately caused by the conventional weapons group and mainly by explosive devices (Fig. 14.1). Even though their prevalence of use is low, it is still important to know and understand the unconventional mechanisms as well as the conventional ones.

14.2.1 Radiological Terrorism

One of the main goals of a terror assault is to create fear and mass hysteria among the civilian population, and no doubt that the mere usage of the term "nuclear radiation" is enough to achieve such an effect, mainly due to the lack of knowledge and the fact that most people imagine pictures from Hiroshima or Chernobyl when they think about nuclear weapons [9].

There are four possible scenarios for the use of nuclear weapon in a terrorist attack [10]:

1. Detonation of a tactical nuclear bomb ("suitcase bomb") in a populated area
2. An intentional sabotage in a nuclear facility
3. Deliberate radiation exposure
4. Detonation of a "dirty bomb" – a combination of a nuclear and explosive device

There have only been a few terrorist attacks, which involved nuclear devices. In 1995, terrorists from Chechnya planted a radioactive source – cesium-137 in a square in Moscow – but luckily they reported it to a local news station before any damage was done. In 2006, a former KGB agent was murdered in London by polonium 210 in his drink [9].

The three important elements in the approach to treating radiation-exposed patients are the time since the exposure, the distance from the radiation source, and the possible shielding the patient had. In most cases of radiation exposure, the patients are not emitting radiation to the environment thus would usually get the same treatment such as any other trauma patient. The most important thing to do before the treatment is to take the patient's clothes off since it has been proved that by doing so the radiation exposure of the treating staff could be reduced by 85–90 % [11]. Usually, the skin serves as a very good barrier against radiation so the chance of internal damage from radiation is low. However, if the skin is injured, proper irrigation and debridement should be sought, without primary closure of the wounds.

The time until systemic manifestations of radiation exposure start to appear is one of the most important factors in assessing the amount of exposure – the shorter it is, the greater the exposure. This is one of the reasons why surgery should take place in the first 48 h, before bone marrow suppression ensues. However, if the complete blood count (CBC), and specifically the leukocyte count, stays unchanged for 24 h, it is reasonable to assume no further damage should take place and the patient can be treated as if he was not exposed to radiation [12].

14.2.2 Biological Terrorism

According to the American Center for Disease Control (CDC), bioterrorism is "the deliberate release of viruses, bacteria, or other germs (agents) used to cause illness or death in people, animals or plants. These agents are typically found in nature, but they could possibly be changed to increase their ability to cause disease, make them resistant to current medications, or to increase their spread into the environment. Biological agents can be spread through the air, through water, or in food. Terrorists may use biological agents because they can be extremely difficult to detect and don't cause illness for several hours to several days. Some bioterrorism agents, like the smallpox virus, can be spread from person to person and some, like anthrax, can't" [13].

The common belief is that terrorists' approach to biological weaponry is very limited, but actually, there have been some attempts to use biologic agents as a weapon, for example, the anthrax envelopes in the USA in 2001 [14].

A biological weapon is made up of four elements [15] – the toxin itself, the munitions (the envelope of the toxin), the delivery system, and the dispensing system. The biggest challenge in facing a biological terror event is the rapid identification of its activation. When the activation is triggered by an explosion, it may be easier to identify, but whenever a different dispensing system was used – such as aerosol or water contamination – it may take several days to understand that a biological terror act took place. A rapid integration of data from many sources should be made, for example, schools reporting a lot of absent students or hospitals treating an unusual number of patients with the same complaint, 911 calls, increased demand for over-the-counter medication in pharmacies – all these together should alert the authorities that something is wrong [16].

14.2.3 Chemical Terrorism

Much like in radiological or biological terrorism, only a few attempts have been made in the last three decades to harm civilian populations using chemical agents. In 1984, seven people died after using cyanide-labeled Tylenol in the USA. In Japan, the terrorist organization known as Aum Shinrikyo released sarin nerve agent in a residential area in 1994 causing 6 fatalities and 600 wounded, and again into the Tokyo subway, a year later, this time killing 12 people and injuring over a thousand. About 20 % of the fatalities and wounded on both occasions were from the first responders teams [17].

Materials which can be used as a chemical weapon are usually classified according to the body organ they attack – nerves, blood, respiratory, skin, and lately two more groups were added – riot control agents and paralyzing agents. The substances most often used for terrorism are in a gaseous form since they are easier to acquire, they are relatively easy to handle, and they spread around more efficiently thus having the capability to harm more people [16]. Since most of these materials are colorless and odorless, they are hard to track, and the same clues that applied for the detection of biological weapon apply here as well – large number of patient with similar symptoms, sudden death of previously healthy people, unexplained death of animals and plants, and rapid development of symptoms after exposure to an infected area [18, 19].

The treatment prior to the identification of the chemical agent used in the attack is symptom based. When suspicion rises, the hospital and emergency teams should apply the local emergency protocol for such instances (an outdoor front triage post, decontamination area with washing capabilities, etc.). Unfortunately, antidotes exist only for cyanide, several nerve gases, and a paralyzing agent named BZ, so every other exposure could be treated only by decontamination and supportive treatment [20]. Again, the same as with biological attack, if a combined injury (chemical + traumatic) has happened, copious irrigation and debridement of exposed tissues should take place as a primary treatment step.

14.2.4 Conventional Terrorism

As mentioned above, several possible mechanisms could be joined under the heading of conventional terrorism. The injuries sustained due to these mechanisms are not fundamentally different from any other non-terror-related trauma, with the exception being explosion injuries.

Explosion injury is different and thus separates itself from the other conventional mechanisms in several ways. First, it is quite rare to find an explosion event with mass casualties that is not terror related in everyday life. Second, the mechanism of injury is unique with different and more severe injuries [21], and third, as shown above, no other conventional or unconventional weapon system employed by terrorists causes that many casualties (Fig. 14.1).

In order to better understand explosion injury, one has first to understand some physical basics regarding explosions. When a bomb detonates, there is a very rapid transformation from a solid or liquid state to a gaseous state. The gas spreads outward in a radial fashion as a high-pressure blast wave [16] at supersonic speed. The air condenses rapidly in the edge of the blast wave and creates a shock front. The wave itself and the air movement it propels (named blast wind) follow the shock front. In ideal conditions in the open air, the intensity of the wave should decline with time according to the time–pressure curve (Friedlander curve), but nevertheless, there are some variables that might influence the energy scatter, such as a blast in a confined space. In a closed space, the wave is pushed off the walls and its intensity could be increased up to ninefold [22].

The type of explosive also plays an important role in determining the intensity of the blast. High-energy explosives, such as TNT, Nitroglycerin, C4, Cemtex, Dynamite, and ANFO, will create a faster and stronger blast wave, while low-energy explosives such as gunpowder, pipe bombs, and Molotov bombs will create more thermal energy which might cause more burns [22].

Through the understanding of the blast mechanism and its physics, one can understand why explosions cause so many casualties with such complicated injuries, in contrast to other conventional terror mechanisms. Comparisons made in Israel between non-terror-related and terror-related trauma casualties from explosions

Fig. 14.2 Acute traumatic amputation due to an explosive device. Notice the fracture through the shaft and the massive damage to the soft tissue (courtesy of Dr. Norman, Rambam University Medical Center, Haifa, Israel)

demonstrated significant differences in the ISS scores, the complexity of the injuries, the need for operative treatment, the number of ICU admission days, and, of course, mortality rates – all of which were higher in the terror-related trauma group [23–28].

The mechanism of injury from explosions actually entails four different injury mechanisms – primary blast injury (PBI), secondary blast injury, tertiary blast injury, and quaternary blast injury.

14.2.4.1 Primary Blast Injury

This primary injury affects mainly hollow organs with an air–liquid interface, as a result of the blast wave impact. The most vulnerable tissues are the ears, the lungs, and the GI tract. Damage to the eardrum can actually be used as a marker of exposure to high pressure [29]. The pulmonary injury could be very severe and eventually lead to the development of ARDS and death, even in casualties who survived the initial explosion [30].

From an orthopedic point of view, the main injury type through the mechanism of PBI is acute amputation (Fig. 14.2). This type of amputation usually happens through the shaft of the bone and not through the joints, as was demonstrated in a study on blast injuries from Northern Ireland in 1996 [31].

14.2.4.2 Secondary Blast Injury

This mechanism of injury is the one that causes most of the orthopedic limb injuries. In this mechanism, the injury happens from shrapnel and free bodies flying all around at a very high velocity as a result of the blast wave. The shrapnel could be parts of the bomb casing or parts of the bomb mechanism (primary fragmentation) or parts of an object, which were in proximity to the bomb (secondary fragmentation) [32]. Specific metal parts imbedded within the bomb by the terrorists such as bolts, nails, screws, and metal balls are common findings in improvised explosive devices, and are used to increase the damage and to compensate for lower-grade explosives. These types of injuries might cause severe soft tissue damage along with open fractures [33] (Fig. 14.3).

Two rare examples of secondary fragmentation injury have been described in Israel and the UK [34–36], when body parts of the suicide bombers got embedded within bodies of the explosion casualties. This kind of exposure might have long-term effects, especially if the terrorist was a carrier, by accident or deliberately, of an infectious disease such as HIV or hepatitis.

14.2.4.3 Tertiary Blast Injury

The tertiary mechanism is caused by the impact of the thrown body against a hard surface, as a

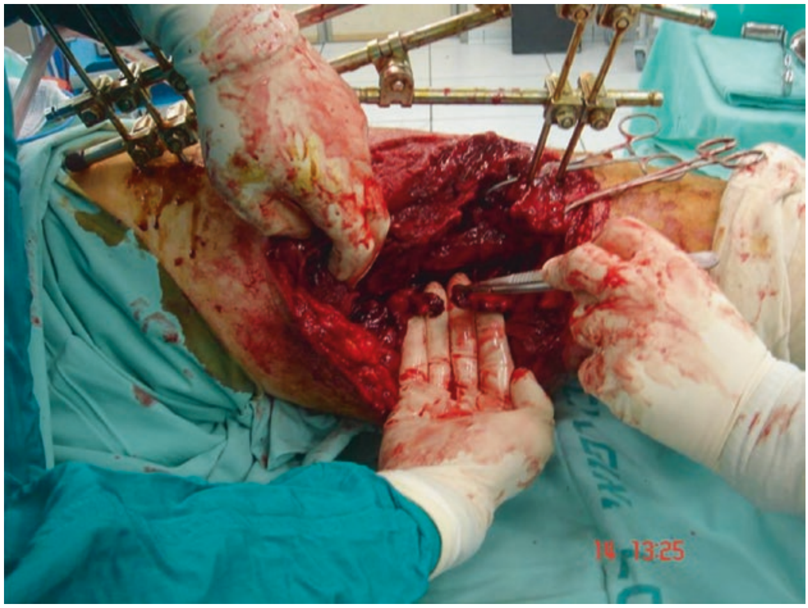

Fig. 14.3 Gustilo 3A open femoral fracture due to shrapnel injury. Notice the torn Sciatic Nerve. (courtesy of Dr. Norman, Rambam University Medical Center, Haifa, Israel)

result of the explosion. Such trauma can cause limbs and spinal injuries, head injuries, and other blunt injuries. Children are more susceptible to this type of injury mechanism because of their lower body weight [37]. Usually, these injuries are not life threatening on an immediate basis but could deteriorate the patients' condition rapidly if not diagnosed on time.

14.2.4.4 Quaternary Blast Injury

These injuries, sometimes called "miscellaneous," are caused by indirect effects of the blast, such as burns due to fire eruptions, smoke and dust particle inhalation, and crush injuries from collapsed structures. Perhaps the most known example for this type of injury mechanism was the 09/11-terror attack on the twin towers in New York, where most of the casualties were injured by this mechanism.

This type of mechanism is the one that "dirty bombs," which combine a nonconventional weapon with an explosive device, are based on [38]. However, even though the blast should cause the "dirty" material to spread to the environment, it usually destroys the material, and the nonconventional element of the bomb does not work. This was the case in the explosion at the World Trade Center in New York in 1993 – the device contained enough cyanide that could theoretically contaminate the entire lower Manhattan area but was luckily destroyed by the blast [39].

Lately, this category was expanded to entail psychological injuries and complications related to the exposure to blasts. It has been proven that delayed treatment in symptoms such as insomnia, anxiety, and abstinence could lead to the development of PTSD among the casualties and the rescue teams [40].

14.3 Triage

Triage is the process of sorting and prioritizing of casualties based on their severity of injury and urgency of treatment needs [38]. The skill and training of triage are becoming more important with mass-casualty events such as a terrorist attack, when a large amount of casualties can be expected to arrive in a short period of time. The pivotal post of the triage process is that of the "triage officer" – the person actively responsible for doing the sorting of patients.

The primary classification of patients in a mass-casualty event divides them into four major groups [41]:

1. Immediate – the most severely wounded patients requiring immediate treatment to save their lives.
2. Delayed – patients who do not require immediate treatment, including those who enter the ER on their feet.
3. Expectant – severely wounded patients whose complex treatment might require a lot of resources and time, which might be used to treat and save the lives of many more salvageable casualties. The definition of the patients in this group can change according to the event that took place and the casualties load in the specific hospital.
4. Dead on arrival.

The most important principle leading the triage officer is to deliver the greatest good to the greatest number of patients [42]; thus, the most difficult decision this person has to make is regarding the treatment of the "expectant" group. It is this principle that makes the difference between a terror-related mass-casualty event and regular trauma treatment – while in a regular trauma setup, most of the resources will be diverted to treat the most severely injured, in this terror-related setup, a decision should be made to allocate resources to the larger group of less severely injured patients. Nevertheless, when the event has been contained, a second assessment has to be made regarding these patients in the expectant group [43, 44].

Sometimes it may be quite difficult to rapidly assess a large quantity of casualties at once, especially when the triage officer knows that every decision he/she takes might endanger many lives. Research on American casualties from Iraq tried to isolate specific injuries that could be used as prognostic factors for early demise and demonstrated that the presence of two or more of the following variables could significantly raise the mortality rate – hypotension, 3 or more broken long bones, penetrating head injury, and other fatalities in the same traumatic event (20 % for a single variable and 86 % for two and more) [45]. Another study conducted in Israel on 798 terror-related casualties found a significant relation between the development of blast lung injury and penetrating head injuries, large burn area (over 10 % BSA), and skull fractures [46]. Age is another very important factor – elderly patients might have other diseases that are not related to the trauma, which might render their treatment more complicated in a terror-related event [47]. These prognostic factors could help the triage officer to allocate the casualties into the different groups more accurately though there is no replacement for clinical judgment and training.

Regarding the accuracy of triage, there are two important issues to recognize: "under-triage," which is the allocation of casualties from the immediate group to the delayed group, thus preventing urgent treatment from those who need it most, and "over-triage," which is the allocation of patients from the delayed group to the immediate group, thus increasing the load on the medical team and resources and by doing so maybe even preventing treatment from more emergent patients. Actually, in the treatment of non-terror-related trauma patients, it is quite accustomed to do some over-triage since usually there are enough resources and personnel to treat severe injuries. Under-triage, however, is always dangerous [48]. The best way to try and minimize these two common mistakes is by training the local triage officer in the identification of injuries and their prioritization.

The ability of a hospital to receive and treat a large number of casualties depends on its preparedness and the number of available staff at that specific time. A proper preparation of the ER to a mass-casualty event could almost double its ability to receive casualties per hour from 4.6 to 7.1 [49]. This concept was employed successfully in the design plan of newly built emergency departments in Israel – the Hadassah University Medical Center in Jerusalem and the Soroka University Medical Center in Beer Sheva, which can both double their ER capacity upon a few minutes' notice.

In the process of triage, there are usually three crucial "tight spots" within which the incoming casualties could get stuck. The first one is the primary triage process of the triage officer. Upon his decisions, the casualties are allocated to their group and treated accordingly. Each group has its own site manager and usually several treatment teams lead by a general surgeon and an orthopedic surgeon. The patients are assessed according to the ATLS protocol and are then transferred to the next station – direct hospitalization, imaging studies, or the operating rooms [50]. If the triage officer will not be able to sort the incoming casualties quickly enough, then treatment could get withheld and lives could be lost.

The imaging studies are the second "tight spot." This is a very crucial point especially in terror casualties, since a lot of them will have shrapnel and other penetrating injuries which will require imaging, and usually, in modern level-1 trauma center, these will be CT scans. A tight spot at that point means the patients are awaiting their imaging study and theoretically could deteriorate while doing so without full awareness of the treating teams. A solution to this problem was utilized in the year 2005 after a terrorist attack in London, when the trauma teams decided that due to the large number of casualties and the great burden on the CT suite, only casualties sustaining head injuries will have an emergent CT scan, while explorative laparotomies where decided upon by using ultrasound devices, deep peritoneal lavage (DPL), or merely an acute drop in blood pressure [51].

The third "tight spot" are the operating rooms, and the team leaders must time the operations according to their urgency. About 50 % of the casualties in a terror-related mass-casualty event will require surgery, and most of these are orthopedic procedures [52], so the orthopedic surgeon must be a part of the trauma team and take an active part in the decision making regarding the operative timing.

14.4 Evaluation and Treatment

14.4.1 Patient Evaluation

As mentioned above, the assessment of a patients' condition should be done according to the principles of the ATLS scheme and as soon as possible [33]. In this manner, life-threatening injuries will get priority and be treated first. The treatment of the remaining non-life-threatening injuries will be postponed until the patient's condition is stabilized.

The role of the orthopedic surgeon in this primary stage of treatment is to identify life-threatening orthopedic injuries (such as pelvic fractures), to identify apparent long-bone fractures and temporarily stabilize them, to complete the skeletal physical examination with great emphasis on the neurovascular part of it, and to order the necessary imaging studies in order to complete the primary assessment of the patient [53]. It is worth mentioning that the presence of a long-bone fracture is indicative of a high-energy trauma injury with a high ISS score, which could lead to major morbidity and mortality [33], same as pelvic and spinal fractures. The neurovascular examination of an injured limb is of high importance as well, though sometimes it is not enough, especially in explosion scenarios. In a study conducted on improvised explosive device (IED) casualties, the researchers found that among 25 % of the patients with a normal physical examination, angiography demonstrated a significant vascular injury and 18 % of them required surgery for it [54].

Primary orthopedic treatment should begin in as early as that stage and might include reduction of dislocations (the longer a joint is dislocated, the greater the potential damage to the cartilage and neurovascular structures surrounding it [55]); reduction and casting of closed fractures and thus minimizing patients' pain and, again, neurovascular potential complications; washing open wounds with copious amount of sterile fluids; and administering antibiotic treatment and anti-tetanus vaccination [33].

The next stage will usually be imaging studies. These will usually include regular *x-ray* and *CT scans* and are used to asses and classify the severity of the injury, thus guiding the treatment [56]. In most cases of limb injuries, plain x-rays will supply enough information to guide treatment; however, sometimes a CT scan is warranted, especially with the involvement of pelvic fractures, spinal fractures, and periarticular injuries. Shrapnel injuries are also accurately assessed with the aid of CT. *Fluoroscopy* is another important imaging modality that could be used inside the surgery room for diagnosis and treatment and can even save the patient important time if it is utilized instead of regular x-ray in cases when the patient has to be rushed into surgery. *MRI* scans are very accurate and could give detailed information but are usually time-consuming and since a lot of the limb injuries, especially in explosion scenarios, involve penetrating objects from unknown sources, these scans are nor recommended in an emergent basis [56].

14.4.2 Treatment: Damage Control Orthopedics

The treatment in multi-trauma patients with complex orthopedic injuries has gone through fundamental changes in the last 50 years. Until the late 1960s, it was accustomed to treat these patients' long-bone fractures with traction alone, the leading thought was that these patients are too sick to be operated on. The fear was that the surgery to fix the fractures might induce fat emboli, and the patients were operated on (if at all) only after long periods of traction, which in turn caused a lot of morbidity and long-term dysfunction of the limbs [57].

Towards the end of the 1960s, with the emergence of the AO organization, a conceptual change has been introduced so that every patient was operated on immediately and definitively upon arrival, according to the new principle of "early total care." The leading slogan was now "the patient is too sick *not* to be operated on." At first, this approach was only clinically based, but in the 1980s, prospective studies began to appear with strong evidence regarding its advantages. These studies demonstrated significantly lower rates of pulmonary complications such as ARDS, pneumonia, and fat emboli in patients whose femur fractures were treated with an intramedullary nail (IMN) on arrival [58]. Concurrent decline in ICU admission days and total admission days was observed.

The pendulum swung again in the 1990s due mainly to two major developments. The first was the development of the damage control treatment protocol in general surgery trauma on the basis of the discovery of the inflammatory storm mechanisms in multi-trauma patients [59]. The second was the emergence of primary reports on actual rise in pulmonary emboli rates among patient who were treated with an IMN within the first 24 h of their injury [60], which contradicted the former data. These two developments led to the development of the damage control orthopedic (DCO) approach.

The DCO approach is based on the "two-hit" theory. The "first hit" is the trauma itself which induces an acute inflammatory response in proportion with the severity of the trauma [60]. This inflammatory response is characterized by high level of cytokines (mainly IL-6 and TNF-α) and other inflammatory derivatives and could lead to respiratory failure and multi-organ failure (MOF) [61]. When the first hit is not as severe, the body will usually be able to cope appropriately. However, when on top of the body's response to the first hit comes a "second hit" in the shape of surgery or sepsis, a critical inflammatory response will ensue, and the chance for developing ARDS and MOF will increase.

The principles of the DCO were developed in order to deal with the dangers of the "second hit" and basically state that the orthopedic surgeon must assess the patient's condition and decide whether to treat him immediately and definitively or rather to do only primary stabilization of the fractures using external fixators and postpone definitive surgery to a later date after the patient's condition stabilizes.

Many attempts were, and are still, made to build more accurate tools in order to better assess the multi-trauma patients' inflammatory state and make the treatment decision easier, but no such tool is yet available [62]. In light of that, the treatment decision remains to be clinically based. The multi-trauma orthopedic patients are divided into four categories: stable, borderline, unstable, and in extremis. A *stable* patient could usually be taken to the surgery room for definitive treatment immediately. The *unstable* and *in extremis* patients will be treated according to the DCO principles and only later on, once stabilized, could have the definitive treatment. The *borderline* patients are a treating dilemma. Usually these patients suffer other injuries as well such as chest, abdomen, or head trauma, with high injury scores, which puts them in high risk for prolonged surgical care on arrival. In most cases, these patients will also be treated according to the DCO principles [61].

The timing of the definitive treatment for patients treated according to the DCO principles is crucial. Studies demonstrated that patients who had definitive surgery in the 2nd to 4th day after the injury suffered from higher rates of MOF, in comparison with patients who were treated definitively on the 6th to 8th day post injury, so the orthopedic surgeon must always recognize and try to avoid the second hit [63].

In the last few years, the DCO principles are utilized in cases of a single-limb injury as well. Usually these are injuries with extensive soft tissue damage together with a bony injury, which usually mandates primary bony stabilization with an external fixator until the treatment of the soft tissue is done and only then (if still needed) definitive surgery could take place.

14.4.3 Treatment of Typical Injuries

14.4.3.1 Soft Tissue Injury

Many orthopedic surgeons realize today that the treatment of soft tissue injuries is probably the most important part of the treatment, especially with war- and terror-related injuries. In 1994, Coupland reviewed his treatment on 12,000 open fractures and stated that thorough debridement of necrotic tissues and removal of foreign bodies and infectious materials was even more important than fracture fixation when treating an injured limb [64]. He demonstrated that in most cases, one could achieve closure and coverage of wounds within 5 days of the injury. Later studies on US wounded soldiers found increased rates of infections of upto threefold in wounded soldiers who were not treated with early proper irrigation and debridement [65].

The treatment of soft tissue injuries went through changes along the years. Traditionally, these injuries were treated with simple dressings for a long period of time until the wound healed [66]. The tendency today is to actively try to achieve soft tissue coverage and closure of wounds earlier than before. Celikoz described his experience with early definitive treatment of open fractures within 1–3 weeks (average 9.3 days) in 215 severely injured limbs as a result of gunshot injuries, land mines, and IEDs. Most of his patients had two consecutive surgeries of irrigation and debridement within 3 days of injury and on the third operation had definitive treatment both for the soft tissue and the fracture [66]. Celikoz describes major success rates with free flaps procedures – 91.3 % – but states that this was a very large referral trauma center with great experience and that the aggressiveness of the treatment was an inseparable part of the success.

Similar approach was taken by Langworthy et al. who developed a treatment algorithm for mangled extremity injuries as a result of explosions – The Balboa Blast Treatment Protocol [67]. This protocol includes four stages of treatment: first, resuscitative stage of the patient and limb within 1–4 h of injury; second, preliminary stabilization of the fracture and limb, within 1–72 h; third, coverage and closure of soft tissue, within 3–7 days; and fourth, disability treatment, after 7 days (Fig. 14.4).

In the early 1990s, reports were starting to be published regarding the success of the antibiotic beads pouch treatment in reducing bony and soft tissue infection in open fractures. Henry et al. reported on the overall results of 845 open fractures treated with systemic antibiotics versus systemic antibiotics with an antibiotic bead pouch. The infection rate with just systemic antibiotics was 12 %, but with a combination of systemic antibiotics and a bead pouch, the infection rate was reduced substantially to 3.7 % [68]. The local concentration of the antibiotics could be as 10–20 times higher, and the effect could last for as much as 3 weeks, although in a blast injury pattern, the pouch should be replaced every 48 h [69].

The relatively new method to treat soft tissue injuries and open fracture is by using the vacuum-assisted closure device (VAC). Its use is being

Fig. 14.4 The process of soft tissue coverage with a free vascular graft after a Gustilo 3B open tibial fracture due to gunshot injury. **A**. Initial Ex-ray of the fracture. **B**. The extent of the soft tissue injury over the fracture site. **C**. Abdominal scar after harvesting the Rectus Abdominis free vascular graft. **D**. One month post op – the graft is fully imbedded with no rejection. **E**. 1 year post op – the patient regained full functionality (courtesy of Dr. Korngreen, Soroka University Medical Center)

popularized worldwide and encouraging reports are published regarding the success rates with applying it. A large retrospective review of 229 open tibial fractures that were treated with either VAC system (72 %) or conventional dressings (28 %) and compared the infection rates was published recently [70]. The results showed a significantly lower rate of infection with the use of the VAC system (8.4 % versus 20.6 % in concordance). Our local experience is also extremely successful with the use of the VAC system and our protocol mandates that every traumatic soft tissue injury will be dressed with the VAC system at the end of the initial surgery of irrigation and debridement.

14.4.3.2 Fracture Fixation

The treatment of fractures in the setup of terror-related mass-casualty event will be according to DCO principles. The leading rule of “life before limb” should govern hence the fractures will be treated with a quick application of external fixators in order to minimize the operative time in the initial surgery [16]. Coupland stated that the external fixator enables the treatment of the soft tissue injury while maintaining relative stability of the fracture, thus allowing it to heal with the creation of callus tissue and sometimes with no need for an internal fixation procedure later on [64]. This method is applied by the American Army in all campaigns in the recent years [71, 72] and was also extensively used by the Israeli Army in the treatment of the earthquake casualties in Haiti in 2010. The Israeli Army's Field Hospital Unit treated over a thousand patients in 10 days, out of which 73 external fixators were applied for open fractures and femoral fractures [73].

Even though a vast agreement exists regarding the use of external fixators in a terror-related mass-casualty event, there are reports of other fixation techniques in these settings as well. Weil described the experience of the Hadassah medical center in Jerusalem in the treatment of long-bone fractures as a result of terroristic attacks and demonstrated promising results with the use of IMN on an immediate basis; however, in order to treat the patients in that manner, the surgical team has to be highly skilled and the hospital needs to have all the resources available at all times [33].

14.4.3.3 Amputations

Primary blast injury and its crushing shock wave are the leading mechanisms causing acute amputations in terroristic events. The shock wave creates pressure within the bone while crushing it, and the following blast wave completes the amputation through the soft tissue [74]. Traumatic amputation is a very bad prognostic sign and could be a sign to the amount of energy the body absorbed in the blast. The amputation in the lower limb usually happens through the tibial tuberosity and in the upper limbs around the wrist [31].

Whenever a patient arrives with an already complete traumatic amputation, all that is left to do is to irrigate, debride, and treat the wound like any other traumatic large soft tissue injury. However, a more complicated issue is the mangled extremity. The decision whether to amputate the limb or try and save it is a complex and difficult decision which entails not only medical issues but also ethical and social ones. Throughout the years, there were many attempts to build a scoring system that will help with these decisions and maybe the most familiar is the Mangled Extremity Severity Score (MESS) published by Helfet et al. in 1990 [75]. The scoring is given according to four clinical criteria: the extent of soft tissue injury, limb ischemia, hypotension state, and age; a scoring of 7 points and over was demonstrated to be predictive of an amputation. Although this system is easy to use and apply, it has many advocates, and eventually, the decision whether to save or amputate the limb should be a clinical one and has to be made on an individual basis. Other influencing elements have to be taken into account in the decision process, such as other injuries, the neurological status of the patient and the limb, and the vitality of the muscle tissues; plastic and vascular consultations are highly recommended [67].

As with any other injury in the setting of terror-related trauma, the wound has to remain open initially without primary closure. Usually a re-exploration procedure will be mandated after 24–48 h, and sometimes more than one until the soft tissue is clean enough for closure or cover. Today, extensive use is being employed with the VAC system in order to shorten the time to closure, but in any case, the closure should be delayed by 5–7 days post injury [67].

14.4.3.4 Shrapnel Injuries

As mentioned above, the common mechanism for shrapnel injury is the secondary blast mechanism, and the treatment of these injuries is very debatable [76] (Fig. 14.5).

The treatment of a limb struck by shrapnel begins in the ER and includes a thorough irrigation of the wounds, treatment with IV antibiotics and anti-tetanus injection, and sometimes even with packing of the wound in cases of extensive bleeding [50]. Imaging studies and especially CT scans could help with the location of the shrapnel and with the operative planning for its removal when needed. The use of ultrasound was also demonstrated to be very effective for these purposes, and it also has the advantage of locating nonmetal particles [77].

The treatment in shrapnel injury is chronologically divided into three stages – acute, subacute, and late [76]. The acute phase includes removal of shrapnel soon after the injury. The most important element in this stage is the intensive debridement and irrigation of the wounds while using the four Cs for asserting muscle

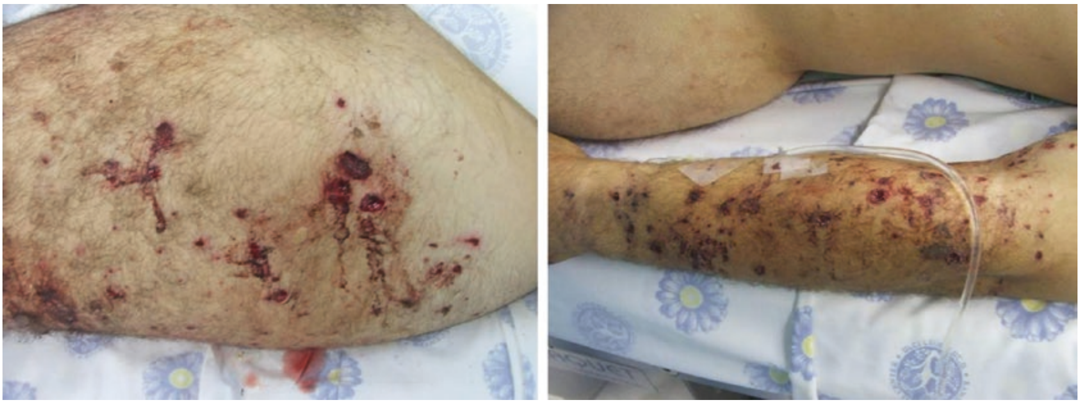

Fig. 14.5 Shrapnel injury in the lower limbs due to an explosion (courtesy of Dr. Norman, Rambam University Medical Center, Haifa, Israel)

vitality – color, consistency, capacity to bleed, and contractility [78]. If during the operation the surgeon finds any shrapnel, he has to remove it; shrapnel not removed will either be removed later or left to stay.

In the subacute phase, removal of shrapnel is done under several indications – suspected infection due to the shrapnel, a periarticular location of the shrapnel (especially in weight-bearing areas due to potential cartilage damage and septic arthritis), a very superficial location of the shrapnel or proximity to neurovascular structures [79], and very large shrapnel.

In the late phase, it is quite rare to find shrapnel that causes the patients any symptoms [80]. However, systemic reactions could develop as a result of buried shrapnel, such as the example of lead toxicity, also known as plumbism [81]. Sporadic reports of cancer cases due to retained shrapnel [82] and the development of aneurisms and abscesses [83] are also points to consider. These, however, are very rare complications and the surgeon must weigh the pros and cons of such an exploration on a late basis. A relatively new partial indication for shrapnel removal is the future need to have an MRI scan [84].

Conclusion

Even though it is almost impossible to conduct randomized controlled trials in the setting of terror-related trauma, the medical information and data collected in the last few decades is enormous. Most of these casualties will have limb and other skeletal injuries and will need orthopedic involvement in their treatment. The orthopedic surgeon must recognize these injuries and their potential complications, mainly infections and the future loss of function, and must know to apply the principles of the DCO in their treatment. We also all need to bear in mind that the treatment of these patients does not end with the last suture of the surgery, since a very long and exhausting rehabilitation period will accompany them and their families for years to come.

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